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The Life-Force
in the Plant World

BY THE SAME AUTHOR

HOW PLANTS LIVE AND WORK
THE MAKING OF A DAISY

THE
LIFE-FORCE
IN THE
PLANT WORLD
OR CREATIVE NATURE

By

ELEANOR HUGHES-GIBB, F.L.S.

Author of *How Plants Live and Work*, *The Making of a Daisy*, *etc.*

WITH ILLUSTRATIONS

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FOREWORD

To those who would like to know the Object, Plan and Scheme of this book before they under-ake to read it;

OR LAST WORD

To those who prefer to use it so.

LET me begin by some words not my own, because they express clearly, and I think beautifully, what I believe to be a great Truth and one sorely needed in these days of nerve-strain and all its attendant ills. The following passages are taken from the concluding lecture of the course of Gifford Lectures for 1915–16, delivered by Professor J. Arthur Thomson, M.A., LL.D., and collected under the title of *The System of Animate Nature*, published in 1920. "Let us think," he writes, "of the way in which Nature contributes to the hygiene and healing of our minds, so apt to be disturbed by the rush and racket of civilization. There are deeply-rooted, old-established, far-reaching relations between Man and Nature which cannot be ignored without loss. Man was cradled and brought up in

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FOREWORD

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"Man needs to sojourn with Nature in order to get certain fundamental impressions without which he is impoverished. . . . Man cannot safely dispense with the fundamental impressions of power, of largeness, of pervading order, of omnipresent beauty, of universal flux, of intricacy of growth, of the web of life, of adaptiveness, of evolution. Some minds weary of theories; let them, by sympathetic observation, hug the facts close, for thus also may deeper visions of reality be gained. Let them by observation draw water from what an expert naturalist has called 'the bottomless well of surprises'." (Chalmers Mitchell, *Finite Life and Individuality.*)

"Another healing virtue in Nature is to be found in its perennial problem-setting interest. It arouses our attention; it intrigues the curious spirit. . . . Its study is a brain-stretching exercise, and while it rewards the discoverer with both light and power, it subjects him to a discipline which engenders humility. For is not all our science rounded with mystery—mystery as to essences, mystery as to origins, mystery as to mutations? What we are surest of is the fundamental mysteriousness of Nature."

Every word of the above expresses my own feeling so closely that I realize that these thoughts are in the air, that they are vibrating, like the wireless, from the brains of thinkers of to-day for those to catch who happen to be in tune. I recognize that the visions one gets from time to time of the working of the great Life-Force, which brought ourselves into being, are not mine in any particular sense, but are the silent emanation of the thoughts of man as he is to-day, and have a call for all those who are attuned to them.

Professor Simpson in his book *Man, and The Attainment of Immortality* says: "One of the imperative needs of this generation is the work of men with minds like those of Albert Magnus or Thomas Aquinas, men who shall see things steadily, and see them whole, and who, starting from that knowledge of the world which men call Science, shall be able to reach up to that more ultimate and comprehensive knowledge of the whole which rises into Theology."

That such stars may arise in our firmament I for one am willing to pray! Perhaps the felt want is already beginning to bring its own supply, for to my mind the Gifford Lectures given by Professor Thomson, from which I have quoted the few passages above, do, amongst others, respond in a very considerable way to the need expressed by Professor Simpson.

The need apparently is for Nature and for that which transcends Nature and makes it whole. For that which without explaining what is obviously in our present state inexplicable may yet shew a possible pathway through the confusion and the mist, to a position far beyond our sight where we can conceive of wholeness and satisfaction.

These are high hopes and to many a mere chimera, but the fact that the aspiration exists and grows in intensity does seem a promise for the future, for though it tarry long, the fulfilment of men's instinctive dreams and deep desires is apt to come in its appointed time.

Meanwhile, in order to dream such dreams or experience such aspirations, we must at least come close to Nature, and listen awhile and try to see what is going on. "Nature" appears to many rather like a thick and tangled wood, filled with briars and innocent of pleasant pathways; it may be full of wonder, but where shall one begin and how avoid getting lost in the tangle? People often offer to take us little excursions into the wood, and we are led in by a clear little pathway prepared for us, and are shewn a number of delightful and interesting things, and we come out again quite pleased and refreshed, but we are no nearer making excursions for ourselves or cutting our own tracks in definite directions. If we could get some general idea of how the land lies, so to speak; if we had an idea where it would be useful to cut a track, in what direction to seek for special adventure; if, in short, we knew at all what we wanted to do—then it might be worth while to make even a considerable effort to get somewhere! Furthermore, suppose we could be given a thread, just as a temporary guide, till we could find a better for ourselves, which would lead us through a definite section of the woods, not shewing us everything, but taking us to interesting places, leading us past fascinating alleys down which we might promise ourselves to make our own explorations later, giving us the chance to take in the character of the woodland and its contents, and finally bringing us out with at least a notion of the general plan of the planting and of the way to explore and what to expect in that section through which we had been led, might not this give a very different aspect to the adventure?

It is something like this that I want to do in this little volume. To provide a thread which may serve as a guide, to suggest lines of thought, to incite, to interest, to lead on till a whole group of ideas are gathered together into a harmonious whole.

The thread which I have chosen for a guide is the Life-Force at work in the plant world, and if we can watch it at work there we shall quickly find that there is no dividing line between its methods in the lower and in the higher forms of life. The same principles and urgings pervade the whole of Nature, though gradually evolved and slowly made visible. The beginnings of these principles are deeply interesting, and the search for the meaning and " will " of the silent Life-Force is a fascinating one.

Nothing in this world is " cut and dried " ready for use; everything is changing and growing, and those who want hard and fast and clear facts and statements of facts should seek for them on another planet or some other state of being. But this need not disappoint us, for we are receiving such portions of the elusive Truth as we are fit for, all the way, and She is leading us on as She flies, to the place where the Whole dwells, which at present we may not conceive.

The facts that I use in this "excursion through the wood" are as well authenticated as my utmost care can provide; the deductions and suggestions arising from them are merely offered for consideration.

Every chapter in this little book must permeate or underlie every other chapter if the book is to be true to Nature. No aspect can be complete in itself, and every separate part belongs to the Whole. A true view of the Whole can only be gathered by the amalgamation in the mind of all the parts. To dwell exclusively upon one idea is to lose the wood in the trees, and this, I think, at the outset is strictly to be avoided. A remedy is to keep a thread—such as the orderly sequence of ideas which I am here suggesting and supplying—steadily in mind whilst we verify and grasp the facts upon which the ideas are based, and work out in our own minds their meaning in the general scheme. For those who like to have the thread in their hands at starting—and I think this is both a real help and an encouragement in the effort of a start through an unknown country—the following indication of the track I have tried to mark out may be useful.

In the first chapter, glancing from some vantage point over the wide view and prospect before us, we feel the need of some one unifying Thought, something to guide us in following the work of the Life-Force, and this we find in the *Spiral* which, from the growth of planetary systems in untracked regions of space, to the microscopic forms of life in the depths of our oceans, appears to be a deep-lying and significant sign, expressing the way in which the Life-Force acts upon material things, bringing them ever onward and upward to an unknown goal. We track it in the stars and in the course of our nearer heavenly bodies, we find it in the bodies of animals and in our own, in shells and horns, and finally in the plant world, where in the end we are brought to that which has long been to me the sacred "Swastika"—the common fir-cone, with its series of spirals running this way and that in clear view of our eyes, and the strange enigma of its great hidden spiral taking in every scale in the cone and carrying all beyond the sight of our eyes. I have shewn how this hidden spiral may be exposed and proved in this chapter, but have left the explanation of its rhythm for the next.

In Chapter II, I have tried to shew how Rhythm, which is a prevailing and deep-lying method of the working of the Life-Force, is written on the leafy branches of the trees, in the arrangement of leaves on the stem, as they are formed at the growing point; in the order of the scales of the pine-cone, and of the petals and other parts of flowers. The orderly sequence of the phyllotaxian numbers which form the basis of the leaf rhythms are shewn, and a wonderful system of arrangement comes into view by which each leaf is so placed as to obtain the greatest amount of light and air for its work in manufacturing food for the plant. I may note, incidentally, that here we find rhythm in the growing points of the leaves distributing them in a rhythmical spiral around the stem, whilst in the later chapters of the book we find it in the visible movements of leaves and in the movements of the sap and other organic functions.

Finally, I have tried to shew that though often hidden and masked, as in the whorls or circles of leafage in many plants, the spiral rhythmic numbers are still to be traced underlying the whole, and that beneath all the apparent disorder and carelessness there is true unity and obedience, which may be laid bare by a careful and patient investigation. Part of this chapter is necessarily very technical and rather difficult to follow, and I have explained that it can be omitted by those who are not sufficiently interested to give the close attention necessary.

In Chapter III, we come to the behaviour of plants in response to the urging of the Life-Force, and to the twin command (explicitly mentioned in the 5th Chapter) to find sustenance wherewith to build their body, and faithfully to reproduce their kind. Difficulties in the way of fulfilling the first of these leads to special adaptations, and we can hardly avoid the idea or *choice* on the part of the plant in the manner of its response. After some preliminary explanations, groups of plants are shewn which have taken to a parasitic life more or less complete, and we trace the effect upon their final place in evolution, and question their success in the struggle.

In Chapter IV, turning from them, we embark on the story of a large and successful family of plants which have taken to inviting "paying guests" in the form of bacteria having the wonderful power of fixing nitrogen from the air for the benefit of their host, upon whose roots they establish themselves in little nodules, and from whom they receive in return certain benefits. The story of the lichens, with their composite being or symbiosis, follows, and we are shewn a strange and intimate union of two lowly plants combining to form a totally distinct organism which has remarkable powers of endurance and persistance, and is one of the great pioneers of the world.

The great Central Spiral of Evolution which is the result of the urge of the Life-Force, whilst leaving the parasites to their self-chosen fate of gradual degeneration, appears to be carrying these little co-operatives on with it to success and more abundant life.

In Chapter V, we discuss the fortunes of another group of plants which—again in the struggle to obey the first command of the Life-Force—have taken to another curious method of obtaining supplies, namely the carnivorous plants. They are very fully described, and in the end are judged to have made a false choice and not to have been blessed in it by the Life-Force.

In Chapter VI, we consider the behaviour of plants in respect to the second command of the Life-Force: faithfully to reproduce their kind. The various methods of reproduction are considered, vegetative, asexual and sexual, and the deep meaning and trust involved is discussed, the continuity of the germ plasm being explained. Some examples are given of the modes in the lower plants, and finally we pass to the consideration of the group which has been thought to contain as near an approximation to the typical angiosperm (the higher of the two great orders of flowering plants) as can probably be found. This family of the Compositæ, to which the common little daisy belongs, exhibits in a wonderful degree the principles of co-operation, and of sacrifice for the general good, these two running side by side in its manner of fulfilling the command to reproduce itself. The Life-Force has evidently greatly blessed it, and its members number one-tenth of all the known plants on the earth. The phyllotaxian numbers and its sequences of rhythm are wonderfully displayed on the disc of little daisy and giant sunflower, and here we seem to stand at the very growing point of the great spiral of evolution as exhibited in the plant world.

In Chapter VII, we turn back to the earliest days of Life upon the earth and consider the "choice" made by the two great branches of animal and vegetable world. We trace the confused and intermingling path of their early separation, and realize that though the one may have made the "higher" and the other the "lower" choice yet the Life-Force has had a special blessing reserved for the latter, and has given to it the work of Service and of Sacrifice as its crown.

We seek to discover what power of response to the stimuli of its environment is yet possible to the vegetable, and we consider the cases of specially "sensitive" plants and their movements. We trace the frequently unnoticed responsive movements in common and well-known plants, and in conclusion some practical experiments are suggested, and others that have been made by myself described, which throw light on much that is going on unobserved under our eyes.

Finally, in Chapter VIII, we take Sir Jagadis Chunder Bose for our guide and try to learn from him something of the mechanism of plant response. We find that every stimulus produces a response though not always an outwardly visible one, we realize that there is an extraordinary analogy between the behaviour of animal muscle under stimulus and that of the "neurine" of plants; we realize that no movement and no position in vegetable organs is without definite cause, as a result of balanced response to various stimuli, either immediate or held latent in the protoplasm of the cells. We compare effects of certain stimuli upon plants and animals; and we find in the effect of stimuli held latent in the tissues of plants and expressed in rhythmic pulsations, remarkable analogy with the movements of our own heart. We turn from this study of the mechanism of the plant-body to ask if mechanical response can cover all the ground. The case of the murderous fig of Guiana is suggested as possibly a typical one offering a suggestion of something inexplicable by pure machinery. It seems as if the Life-Force, even acting in the vegetable, had other than merely mechanical means.

Once more, suggested by the resentment of some botanists against Sir J. C. Bose's generalizations with regard to the unity in effect of the response in animal and vegetable organisms, we turn to the fir-cone—our Swastika. We see the two sets of secondary spirals running in diametrically opposite directions, from the same starting point, as do the courses of evolution in animal and vegetable; we see the interlacing of the spirals, and find on certain scales of the intercrossing lines that they meet and are for a moment one. We remember the great Central Spiral upon which all facts and beings, mechanisms and responses are strung, we see that every scale in the vast Cone enters into that glorious, unseen, uncomprehended Spiral leading far, far beyond our thought or imagination or conception, and we no longer wonder at a Unity in Diversity, at meeting points in opposing lines, at baffling and confusing likenesses and unlikenesses, at the intricacy of the great Web of Life which is being wound on so vast a scale into the great Cone of Creation.

CHAPTER I

SPIRALITY

THE title of this little book may seem rather ambitious and pretentious, for it would be a large field indeed to explore if one tried to picture even in a general way the many-sided working throughout the world of plants of that mysterious force which urges all created things onward and upward. Needless to say, I shall only attempt to bring into focus some of the wonderful and interesting things that this Life-Force is doing under our eyes without our being aware of it.

So many of us have not time or opportunity to watch and observe for ourselves, or even to search through the technical and bulky books of specialists in the various branches of science, to find out what others have observed and discovered: and yet the silent work is going on all around us, and we do feel something in the air, something of mystery and of a hidden life and order and beauty, which beckons us on—if only we had time.

It is for those who feel this longing that I am undertaking this work, in the hope that I may open a few little windows for them into a new world underlying the everyday, busy, dusty one, and shew, just here and there, how the Life-Force is urging, striving, lifting that which it has brought into being, and teaching it to obey and yet to be free, to follow the laws of its being, and yet not to be enslaved by them.

If we ask: what is this hidden and mysterious Life-Force? of course there is no direct answer, nor can there be as to any of the elements or ultimate things of life. But we can find out very much about it and even feel something of its purpose and character by observing its workings in Creation.

Let me try to explain some of the ways in which I think we may do this, and what are the impressions left upon our minds. It will then be easier to go on to the details of the workings that I want to bring into focus.

We seem to stand in this mortal life looking out upon Infinity, which stretches out on the one side to the infinitely vast and on the other to the infinitely small. The former aspect strikes most of us with awe, whilst the latter is apt to be overlooked.

Everyone is struck by the star-lit heavens, by wide seas and vast plains fading to the far horizon, which give a sense of endlessness and boundless continuance; whilst the infinitely small is generally veiled from our eyes. A story which has helped to bring home to me the gulf of the infinitely small, lying, as it were, beneath our feet, is a new version of the old tale of the sleeping hare and the creeping tortoise laboriously overtaking him in which some mathematical philosopher puts the hare behind and the tortoise in front and asks how soon the tortoise will be overtaken by the hare. It does not matter how fast they are each travelling, for the remarkable answer given by the philosopher to his own question is independent of any such point: "Never", he replies quite simply, and the reason is logical from the ordinary point of view. Before the hare has crossed the distance between him and the tortoise he must have crossed half that space, and before he has traversed this, *its* half must be crossed. This halving process never stops, for, however minute the portion left, still there is the half of it to be crossed before the whole, and the half of that, and the half of that, and so on for ever. This is the gulf of the infinitely little and, logically speaking, we can never cross it, and all movement is consequently impossible. It is a *reductio ad absurdum* of course, and the ordinary person just shrugs his shoulders and replies: "Well we do get across it anyhow." But the difficulty remains unless we say boldly: "There is no such thing as 'crossing' infinity." We are all at home in infinity and belong to it. Space and time are false and arbitrary limits, though imposed on our present condition, and they create problems and paradoxes like this by their unreality. In so far as we can use the language of the finite world in such a connection we *do* cross infinity at each movement. I have referred to this paradox because it brings sharply to our consciousness the idea of the infinitely small which lies ever at our feet in Nature but is so easy to forget.

These two aspects of Infinity—that of vastness and of minuteness—seem to correspond with two qualities of mind: the wide imaginative type with a genius for organization and large comprehensive planning, and the detail-loving type with orderliness and method carried to the minutest point. The two types are seldom found combined in any eminent degree in one human individual, but in nature we do find this very remarkable combination; and the character which is slowly and gradually unfolded to the patient student of Nature is such a marvellous one that we should be driven to worship this unknown Personality if we had no other means of communion but through the works of Creation. For, alike in the infinitely great and the infinitely small, there is a perfection and a finished beauty of detail which only displays further wealth of wonder at every new view which we are enabled to obtain through higher powers in our optical instruments.

As with all character worthy the name, this character in Nature is true to itself; it is faithful to the law of its own being. So much so indeed that we can and do count with certainty upon the result, and speak of 'obedience to law' in Nature. In so speaking, however, we are apt to forget that it is a *living* obedience —the faithfulness of life to itself—and no conformity to an outward law that binds her. The letter is nothing to her; the spirit is herself.

It is of this living obedience that I wish to speak in this little book. Every leaf in all the tossing greenery of summer grows where it does with a definite meaning and not one of them by chance; there is a rhythm and a special song for every plant and bush and tree if one can read it, as I shall hope to shew.

The arrangement of leaves on a shoot or branch is normally in a spiral; and here at once we come into touch with something which seems to bring the whole of nature into one great thought, and to give us a glimpse of the Life-Force working through it with one purpose and one—though hidden—meaning. For through the whole of creation the spiral is to be found, connected mysteriously with all growth—from the growth of planetary systems to that of the microscopic foraminifera at the bottom of the ocean: obviously no chance, but a deep-lying sign of some law of being beyond our ken, by means of which the Life-Force is shaping things. To us it must always carry an inspiring thought: "Unfinished, unfinished," it seems to cry; "not here the end; onward, upward, beyond the visible, deeper than the comprehensible, higher than the mind can reach." Never a circle: always a spiral, full of hope and possibility, gathering the All into One and bearing it onward to its unknown goal.

Astronomers tell us of constantly new and clearer views of this 'sign' in the sky. "Some recent research," writes Professor James Simpson, "indicates afresh the possibility of the Milky Way itself being a vast stellar procession in a spiral of two turns, and only one of 900,000 other spiral nebulæ that have been observed and catalogued. On the other hand, Kapteyn's picture of the Milky Way as constituted by two intermingling star-streams moving in opposite directions and probably themselves derived originally from two or more spiral nebulæ, is still the most generally accepted view."

Theodore A. Cook writes: "There is little doubt that spirality is becoming more and more widely recognized as one of the great cosmic laws. . . . This has implied the further recognition that in astronomy, as in every other branch of science, one set of facts dovetails into the next, none can be properly considered apart from the rest. . . . In nearly all the apparently fantastic irregularities of the visible nebulæ we observe that spiral conformation which intimates the action of known or discoverable laws in the stupendous enigma of sidereal relationships. The whole history of the heavens, the more it becomes understood, involves more certainly the laws of spirality, from single and comparatively small examples to such vast masses of nebulosity as that which encompasses the Pleiades."

The interest of the above passage will become greatly enhanced for our special purpose in this book when we come to consider the spirality of leaf arrangement. I think that with the alteration of "astronomy" to "botany" and a corresponding change of terms further on the whole passage could be taken as just as true in the plant world as in that of the heavens.

Returning from our glance at the furthest parts of the universe yet revealed to us, and coming to our own earthly round, we see ourselves pursuing our own spiral course around our sun, believed to be moving with all its planetary system towards some unknown goal. The moon, meanwhile, loops her daily rapid spiral round us whilst being carried on inevitably in the vaster course which involves the whole solar system.

Still nearer home, in our own bodies, the spiral is to be traced in strangely various positions and relations. This part of the subject being entirely outside my own knowledge and the scope and province of this little book, I will only quote in support of what I assert a few words extracted from a review in *The Lancet* of T. A. Cook's book *The Curves of Life*. Speaking of "those organs or parts of the human body which manifest a spiral conformation" *The Lancet* says: "The list of such structures in the human body is more extensive than is usually believed, several examples given by the writer . . . being often overlooked. The first example cited is the spiral arrangement of the trabeculæ of long bones, the recent research of Professor A. F. Dixon on the finer structure of the human femur supplying the necessary data." (I interrupt for a moment to explain that Professor Dixon, examining the interior of the upper end or neck of the thigh bone stereoscopically by X-rays found that the lamellæ, or needles of bone, which composed its architecture, were arranged in a wonderful spiral formation of three crossing and interlacing series, very similar in design and effect to the spiral curves employed by bridge-builders to secure the strength of their architecture.) "The spiral vessels of the umbilical cord and of the cochlea" (of the ear) "are classical examples; the ventricles of the heart provide another well-known instance. . . . The spiral arrangement of the ducts of sweat glands and of the lines in certain types of finger prints . . . are less known examples. The spiral arrangement of the great arteries springing from the heart . . . the spiral valve of the cystic duct" (or duct of the gall bladder) "the spiral twist in the ribs and certain other bones are also dealt with. While in some cases the spiral arrangement gives a manifest mechanical or functional advantage, in other cases its significance is obscure or unknown." The writer in *The Lancet* goes on to remark that the man whose work he is reviewing "does not pretend to have solved the problem of spirals in Nature. He simply sees in such formations that there is a deep problem, which, if it could be solved would throw a light on many of the dark corners relating to our knowledge of the laws of growth and development."

The above is exactly the spirit in which one would like to put anything that one may have to say in the next chapter on the spirals of leaf arrangement and the rhythm of their circling. Nothing in Nature can be complete in itself,

self-explaining and self-sufficient: everything is like a piece torn from a larger fabric with raw edges and loose threads on every side stretching out to the unknown. Yet perhaps one may find, hidden away, here and there, a hint for our comfort of a great spiral gathering up to itself in one all the facts and broken fragments of meaning which, though we may never grasp it here with our finite understanding, we may be strengthened to believe in through the clear teaching of Nature herself. But of this I must speak more fully later.

To return to our rapid glance at the spiral formations in Nature. The examples in shells will come into everyone's mind, and there are no more beautiful instances. From the time of our childhood many of us have traced with wondering fingers the flat spirals in the fossil ammonite from Lyme Regis, or the ascending turns in the turret-like trochus or 'painted top' (to use its common name) from various parts of our coast. But every town dweller is, at any rate, acquainted with the common whelk and the periwinkle sold in his streets, and no one can be unaware of the spiral shell of the various garden snails. The latter has apparently been taken from very ancient times as the pattern of a perfect conventional spiral, as shewn for example in the volute of the Ionic column. We notice that some spirals in natural objects turn from right to left and others from left to right. Botanists and conchologists seem to me to be unnecessarily confusing in the different words they use to describe this opposing direction. I think the simplest way is to describe a spiral which keeps the centre of its axis always to its right (winding round to the right as the hands of a clock do starting from 6.30) as a right-handed spiral, and one moving the opposite way with the centre of its axis to the left as a left-handed spiral. And this the conchologists practically do, describing the former as dexiotropic or turning to the right, and the latter as leiotropic or turning to the left. Some botanists and others, however, confuse us by reversing this because the coil of the spiral in the first named begins, if we start from the bottom, by moving towards the left, whilst in the second case the movement is to the right.

I suggest that we keep to the definition of the spiral that goes with the clock as a right-handed one (it is the instinctive spiral one makes with the right hand, the movement made in turning a handle, winding a watch, etc.) and that against the clock as a left-handed one.[1]

Some shells, and plants too, as we shall see, have a persistent turn to the right or to the left, whilst others go sometimes one way and sometimes the other. The reason is one of those things which Nature seems to keep secret from us at present. It is a curious fact for example that, as stated by Theodore Cook, you may pick up uncounted numbers of living whelks on the beach at Felixstowe and the vastly greater number will exhibit left-handed spirals in their shells, as do by far the greater number of shells in general, whilst on the other hand you may gather fossil shells from the same beach and practically every one will shew a right-handed spiral. Why? There seems no answer at present. Yet, as the same writer remarks, if due to chance "it must be one of those vital 'chances' which seriously affect the future both of the individual organism and of the race" since the left-handed spiral persists almost exclusively in these shells whilst the right-handed has practically died out. Some description of Sir J. C. Bose's theories which seem to throw light on these questions will be found in a later chapter.

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[1] In the case of shells we trace the spiral from the bottom upwards, as with plants, though Nature has worked the other way and begun the shell at what is now the top.

Though we have not yet come to the plant world in our search for spirals, I will mention one example of a right-handed spiral which has struck me lately and appears to be quite persistent in every case. It is that of the leaf of the common daffodil, and the spiral curve is certainly remarkable and gives a peculiar character to the foliage. Following with your pencil the line of the right edge of the leaf from its base, you will find it turns gradually till presently it is on the left side and the back of the leaf is towards you, then slowly it curves on till it has completed a whole revolution round its axis and at the tip of the leaf the right edge is on the right as before.

The common daffodil, double and single, and the pheasant's eye narcissus shew this spiral most markedly; in the wild Lent-lily and in some of the newer forms of daffodil there are often quite straight leaves and the curve is only slightly shewn in others. Of course the leaves of snowdrops, hyacinths, scillæ, and tulips are quite straight, and this peculiar spiral twist in the daffodil and narcissus is a puzzle. Why the twist at all, and if a twist, why always in a right-handed spiral?

But our minds seem to bristle with 'whys' as soon as we really begin to watch Nature at work, and I think it must always be so, for enormous as is the mass of knowledge accumulated in all departments of science, so that a specialist must give up years of his life to master all that is known on one small point as related to the rest, yet the whole sum of our knowledge is but a minute fraction of that which remains outside and beyond all human ken.

Returning to the spiral in shells, it is very interesting to find that this formation is repeated in the hidden recesses of many of them in the shape of a spiral thread winding round a thin central column. When a shell is opened by being sawn through so as to shew the ascending columella right up the length of the shell (a very delicate and difficult process), or better still, examined by X-ray photography, it is seen that this thread where it exists (for some shells are without it) has the same number of turns round the columella in each chamber of the shell from the wee ones at the top, made in the babyhood of the fish, to the last big one at the bottom. In some species there is one turn only to each chamber, in others two, in others three, and so on up to eight or even more.

In the beautiful nautilus family, known to most of us at least in pictures, the curve of the spiral with its generous increase for the growing life is thought to be the typical one for life-development and to give the best chances for survival of the species.

It is most interesting to note that the same type of spiral is to be seen by the aid of the microscope in many of the minute foraminifera dredged up from the bottom of the sea. The shapes of these microscopic creatures are extraordinarily beautiful and perfect, and bear out in a striking way what I said above as to the perfection in design and detail of the 'infinitely little.' One needs to bear in mind that in shells the growing point is at the bottom of the spiral, where the fish is constantly forming new and wider walls to his dwelling. With the plant, on the contrary, to which we shall come presently, the growing point is at the top of the shoot or stem, so that the plant may be said to leave his past behind him, earthwards, and the shell-fish above, in the minute beginning of the coil of his shell.

In the tiny embryo of the shell-fish before he comes out of the egg there is a pit or gland which is the origin of the shell, and the latter is gradually formed in successive layers of cells as the animal grows. Apparently in the common snail the skin of the body secretes the necessary material for thus adding to his house. I have mentioned this detail because it bears on a curious and interesting photograph, which was taken at my request, of the grazings, so to speak, of a snail on the whitening applied as a shading material on the glass of my greenhouse. The photograph, here reproduced,

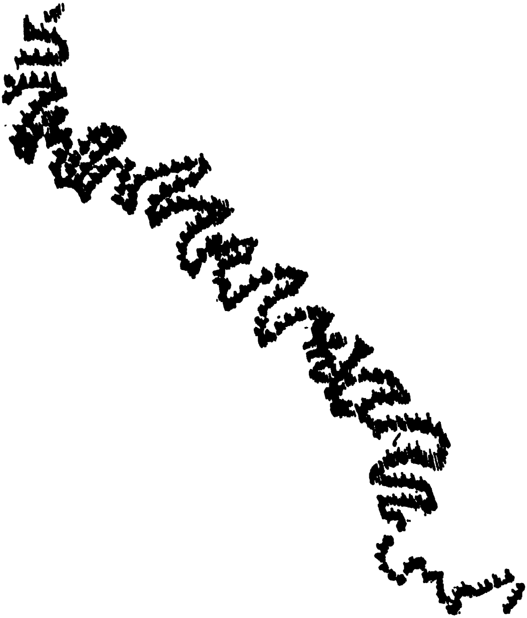


FIG. 1—The Snail Trail.

shews the curious winding of his passage up the glass, the marks of the rows of small teeth upon his broad 'tongue' being very apparent. Now, if one thinks of the movement of his body as he thus turned from side to side and at the same time moved on and upward, one will see that the pressure was always in a forward curve tending to increase the growth in that part and to widen the mouth of the shell's convolution as the animal's reach increased. But the mystery which invests the cause of the unequal growth of the two sides, producing the spiral curve, remains.

In this connection, and leaving the subject of shells for the present, I think of another striking scene in animal life which forcibly brings to one's attention the weaving of the spiral by the living creature. This was a very large caterpillar, who was weaving his own cocoon. He started the business at a rather inopportune moment just as my children, to whom he belonged, were about to take a journey homeward. His box could not be closed as he began work too near the top, so his operations were visible to all. He was accommodated with a place in the window of the railway carriage, and entirely undaunted by noise or vibration he pursued this wonderful and vital work which was to usher in his great change. With extraordinary elasticity he reared his head backwards to wind the fine thread, as he spun it, around his hindmost parts, then further and further the spiral coil encompassed him, and still his head worked on, spinning and winding unceasingly through the hours of that day. It was a fascinating sight. Once our train stopped at a station and it happened that our carriage drew up exactly opposite to the engine of a train on the further rails. The engine driver and stoker caught sight of the little weaver and came to the side of their engine to watch him, absorbed and marvelling at the sight. Could anyone be otherwise? For here was a living worker visibly weaving the spiral of his being before he went to rest within that cocoon of hope.

To pursue a little further our search for spirals in the animal world we will just touch on the subject of horns, where we may find many striking examples. The single horn, or rather the ivory tusk, of the narwhal or sea unicorn is a specially interesting one. In the very early stages of existence he has two tusks, but the right one does not develop and it is the left one which eventually takes the central position and grows to a length of six, seven, or even ten feet—a formidable looking spear indeed! This horn or tusk is furrowed with a beautifully regular left-hand spiral. The home of the narwhal is amid the snow and ice of northern latitudes and in ancient days when its 'horn' was found it was believed to have belonged to the fabulous unicorn.

Amongst land animals are numbers of examples of spiral horns which will occur to everyone. I have several specimens of male black-buck from India with horns making right and left-handed spirals on the right and left of the head respectively, and this is the usual, though not by any means the invariable, arrangement, as, in some kinds of sheep, with horns curving downwards round their faces like curls, the spirals are reversed. Amongst upright spiral horns those of various kinds of antelope, Markhor and Eland are very well known. I have before me an illustration of the head of a species of antelope with rather flattened horns in which the right one follows, almost line for line, my sketch of the leaf of a daffodil described above. In such wonderfully similar lines does the Life-Force, working alike in the plant and the animal world, cause them to express its secret urgings.

When we turn finally to the plant world, which is our special subject, a number of spiral growths will quickly come to our minds. Everyone will think of the tendrils of the sweet pea, the vine, and the passion flower; of those of many of the vetches that grow wild in our hedges, and specially the wonderful coils of the bryony; of the twining spirals of convolvulus, hop, honeysuckle, smilax, and hosts of climbing plants of hedge and garden and of our greenhouses. The dodder—a parasitic plant, less well-known to most people—is a pretty example of a winding spiral. Without a single green leaf, its thread-like pink stems wind its victim in their coil and pass from branch to branch till all are tangled in a mass of network. I shall have more to say of this plant later, but it is interesting to know that the embryo of this curious plant is a naked thread spirally coiled in the seed, so its way of life is implanted in it from babyhood!

The black medick, a tiny yellow flower with clover-like leaves, which often infests our lawns, has some near relations, rarer than itself but to be found in some parts of England, and bearing a strong family resemblance to our familiar little plant, which have their seed-vessels spirally twisted into a prickly ball, and the well-known Calvary clover (a native of Palestine with 'blood-stained' leaves) of the same tribe, has a most remarkable development of the same, which, by thrusting a pin under the coil at the top of the ball, can be drawn out into a perfect spiral, armed from beginning to end with sharp little thorns which interlace to form the ball of the seed-vessel.

The beautiful coil of the young fern-fronds in the early spring must be mentioned (though this is an opening spiral and not the ascending one we are thinking of here) on account of its extraordinary resemblance to the coils of the ammonite and other shells. Searching under the dead leaves at the roots of the withered male and lady fern in the wood, or the hart's-tongue where that grows wild, you will find nurseries of these coiled babies, some of them wrapped in a sort of brown fur and not yet beginning to uncoil, and the likeness to the form of the shells above mentioned will strike you at once. We remember that we have been told it is the curve of growing life.

Deeply hidden in the body of the plant we may find the sign of the spiral woven into its substance. The vessels of full-grown plants are formed by the disappearance of the cell-wall between two or more cells standing one above the other. The sides are thickened by deposit which is not disposed evenly over the whole surface but very frequently in a spiral thread, which can in some cases be drawn out of its tube—in the strawberry for instance—

and can very easily be seen through the microscope in the fibre of the plantain leaf.

But leaving our list of plant spirals to which everyone may add indefinitely by daily observation and experience, I want to bring to your notice what I think is one of the most significant and striking of all Nature's productions—at least in the plant world: and indeed it seems like a key to the spirality of leaf arrangement, if only we can use it. I am speaking of a common fir-cone, and if you can procure a good straight one from the spruce fir or 'Christmas tree' of our childhood, it will best answer our purpose.

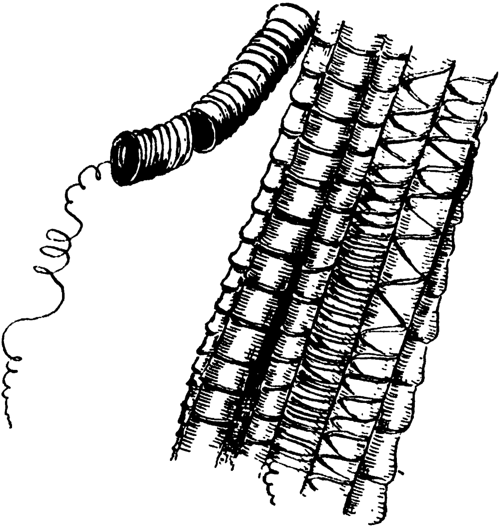


FIG. 2—Vessels from plantain leaf through microscope, shewing the spiral thread which thickens them.

I remarked earlier in this chapter that leaf arrangement, generally speaking, is normally in a spiral, although this is by no means apparent to the casual glance. Now the scales of a fir-cone are in truth modified leaves, changed from the ordinary green leaves of the tree in order to do a different work; and these are actually arranged in a spiral but so crowded together that we lose sight entirely of the central spiral which takes in every scale of the cone, and we only see secondary spirals running to the right and to the left, each of which takes in a certain number of scales in its course. Can we discover that hidden spiral which lies at the heart of the fir-cone masked by the network of

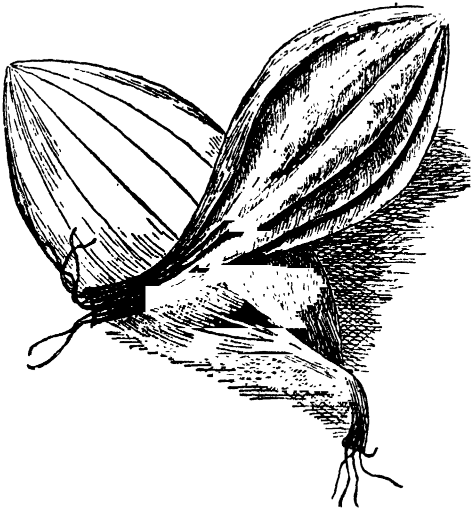


FIG. 3—The plantain leaf with fibres hanging out from broken stalks.

the crossing secondaries? It is not hard to do so when you understand the physiology of the fir-cone. But without going into that, as yet, I want to shew you a simple way in which you can demonstrate it for yourselves and prove it to your own eyes. I am, as I have said before, only speaking here for those who have not had time to study these things for themselves, so I go into all details to make matters as plain as possible.

Strip off a few of the small scales at the bottom of your cone so as to get a good base to work from. You will notice that however many scales you strip off there are always five in each fresh ring that you disclose by so doing. Mark one of these scales as a starting point, and count how many secondary spirals ascend from the base and go round the fir-cone to the right; now count those going to the left. In most cones the number will be eight on the right and five on the left, but this is reversed in a 'left-handed' cone. Now you have to mark each scale with its appropriate number, as I will

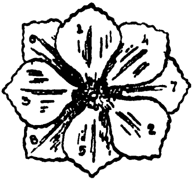


FIG. 4—Showing the placing of the first 8 scales at the base of a fir-cone. From these 8 scales the secondary spirals start; 5 of them from the first 5 going one way, and 8 from the eight scales figured here, going in the opposite direction.

explain. I have done it with ink, but it is not very easy, as the ink dries in and does not shew or else is apt to blot. It has been suggested to me to try rubbing chalk on the scales before trying to write on them, and I certainly think this is a help. But I have found that a fine paint brush with Chinese white paint is one of the best methods, though it is a tedious and tiresome process. However, when you have gone a very little way the matter will be perfectly plain to you and there is no need to go on unless you wish.

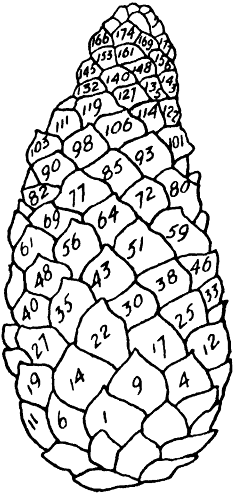


FIG. 5—Numbered fir-cone.

Start on one of the lower scales and write 1 on this. If the cone you have chosen has 8 spirals going to the right and 5 to the left you start from number 1 and ascend the spiral which winds up from it to the right, marking each scale as you come to it with the number of the last one *plus* 8. Thus you will have a spiral running round the fir-cone to the right with the numbers 1, 9, 17, 25, 33, and so on. Now return to No. 1, and pursue the spiral which winds to the left from this scale, marking each scale in its turn with the last number

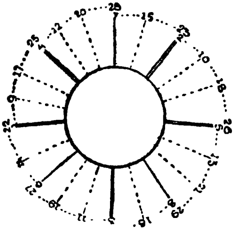


FIG. 6—Diagram of secondary spirals on a cone having 8 spirals to the right and 5 to the left, shewing the order of placing of scales in the central spiral, hidden from view. This diagram represents a cone cut across transversely. The double spokes represent the first 5 scales to be placed around the stem, the single spokes the next three; from these 8 scales the 8 secondary spirals start, winding to the right as shown by dotted lines. The 5 that go to the left cannot be shewn clearly on this diagram, but may be followed by the figures 1, 6, 11 and so on. The central spiral can be read by following the figures in numerical order, 1, 2, 3, 4, etc.

plus 5. You will now have a spiral running to the left and coiling round the cone with the numbers 1, 6, 11, 16, 21, and so on. After this you have nothing to do but to start with one of these known and marked numbers and pursue your way up the spiral in which it stands, adding 8 each time if you are travelling to the right and 5 if to the left. To place some of the lower numbers you will have to go *down* the spirals, and in this case you will of course subtract the numbers 8 or 5 from the scale immediately next in the spiral concerned. By this means every scale in the fir-cone will quickly fall into its place, and you will find that by revolving the fir-cone slowly and finding 1, 2, 3, etc. on the marked scales you will be able to read the hidden central spiral which gathers in every scale on the cone.

When I first accomplished this, many years ago, and I saw my cone—which I had gathered from the woods amongst a multitude of such—with its perfectly ordered array of progressive figures running this way and that, and further orderly sequences to be made out in steeply ascending spirals where 13 (the sum of 8 and 5 of course) was the constant difference between the number of the scales composing them; when I realised that this wonderful arithmetical object had come straight from the hand of Nature, and that it held within it the hidden spiral of which it was composed, which gathered up into one all these orderly sequences—I am unable to describe my feelings. Mathematicians will smile indeed at my simplicity and innocence, but I am not ashamed to say that if God had appeared to me in a Burning Bush I could hardly have been more struck with reverent amazement and wonder. And still the fir-cone is to me an almost sacred thing and speaks to me more clearly than anything in Nature of orderliness and, so to speak, numbered facts winding their way on to some unknown goal of perfection; of limitations to our knowledge and understanding of these facts, the secondary spirals only being visible to us; yet of the certainty of the underlying central spiral which gathers all in one and carries it up to God.

If in this little book I could so much as indicate the trend of movement in one of the secondary spirals in the great cone of universal life I should think myself fortunate indeed, but that is a high ambition.

Of course the fir-cone is not a portent, as in those early days I was almost inclined to regard it. It is no separate and special revelation of the mind behind Nature speaking to us, but is rather the manifestation in a very clear and definite form of that working of the Life-Force which is in every living thing, though its ways are so often hidden from our eyes. In the next chapter I hope to trace the story of the numbers which lie at the root of the fir-cone's formation, and to shew how every leafy bough is subject to an inner law of spirality, which yet leaves it the true freedom of the living thing to vary according to its need. It is this variability, this 'freedom' as one may call it, of all life, resulting in infinite diversity from the mathematically exact, which is believed by some of the greatest scientists to be "the Cause or rather the basic condition" (to quote Alfred Russell Wallace) "of the exquisite forms in Nature, never producing straight lines but an endless variety of curves and spirals. Absolute uniformity of atoms and of forces," he continues, " would probably have led to the production of straight lines, true circles or other closed curves. Inequality starts curves, and when growth is diverted from the direct path it almost necessarily leads to the production of that most beautiful of curves—the spiral."

The late James Hinton thought that " growth under resistance is the chief cause of the spiral form assumed by living things ", and this appears to me to be not inconsistent with Wallace's view. If we watch the curling of smoke ascending from a chimney on a still day, when it meets the resistance of the atmosphere, we shall feel the force of the suggestion. It has been considered, however, that Hinton's " generalization does not cover many of the most remarkable instances ", and examples are quoted sometimes of the 'reasons' for the spiral in special cases—as, for example, the importance to the plant of securing the utmost light and air for its leaves, which a spiral arrangement ensures—but surely this is confusing use with cause, for we are constantly being warned by alarmed scientists of the danger of supposing that a plant or lower animal adopts any useful habit of set purpose! Doubtless through natural selection these results might arise, but can they lie at the very root of things when the spiral is universal? And if different 'causes' have to be found in the cases of the spiral nebulæ, the circling leaves, and the intestines of a frog, surely there is some deeper explanation beyond our sight.

CHAPTER II

RHYTHM IN PLANTS

AFTER realizing the spirality of Nature, the next step is to become aware of her rhythm.

Rhythm plays a large part in her manifestations, for music and numbers seem to be interwoven with our being. A rose, for example, is full of music and number, and it has a perfectly definite rhythm of its own. So has a wallflower, and it is a totally different rhythm. The golden-rod has another, which is really made up of one measure of the wallflower's rhythmic beat and one of that of the rose, and the fir-cone plays two wallflower beats and one rose beat.

Anyone who wants to observe the rhythm in a rose can do so with very little trouble. A rhythm, of course, is just an ordered recurring movement—the sort of thing that makes you a little sleepy to think of. It can become an awful and deadly monotony. If it ends at the conclusion of each beat, exactly where it began, it *must* do so. "One, two, three" . . . a pause . . . "one, two, three", and so on for ever in a circle! it would be enough to drive anyone into a mad-house. But how if the music is ascending with each rhythmic beat? How if it is floating higher and higher, leading up to the unknown in spiral circlings like the song of the lark? Well, the rhythm of the rose does that, and if the rose-shoot did not stop, neither would the ascending music. All the plants and all the trees are singing in spirals: "one, two, three" . . . "one, two, three"

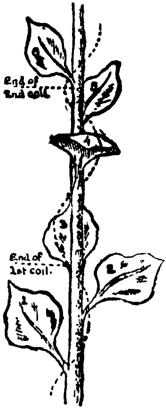


FIG. 7—Matipo shoot shewing the $\frac{2}{5}$ rhythm. Rose has the same rhythm.

. . . "one, two", or whatever their special rhythm may be, and some are playing quite complicated music if only we can read the score.

This is how to begin to do so.

Take a long vigorous rose-shoot and tie one end of a long piece of cotton to the bottom leaf. Now twist the cotton carefully round the base of each leaf as you come to it, all up the shoot. That is all; for the cotton in its spiral passage up the stem will have brought to light the hidden music. Round and round goes the white coil, passing three leaves in its first complete turn round the stem, and two in its second and then finding a leaf exactly over the one you tied it to. Here it starts again and does the same thing, finding three leaves and two leaves alternately in its coils and then returning to a point just over its start. This rhythm of three leaves in one turn and two in the next is the rose's simple music; 3, 2; 3, 2; 3, 2; for ever in a spiral up the stem till it runs off into space to sing amongst the stars.

You perceive that the cotton in two turns passes five leaves, and then—and not till then—finds one exactly over the leaf it started with. This is the $\frac{2}{5}$ rhythm, and if you would carefully measure the distance of leaf from leaf as regards the circumference of the stem, you would find they were just $\frac{2}{5}$ of the circumference each from each.

The rhythm of the wallflower and holly is a little longer. The coil of cotton passes three leaves in its first turn, three in its second, and two in its third, and then comes (at its 9th leaf) to one just over the start. The leaves are $\frac{3}{8}$ of the circumference of the stem apart, and in three revolutions eight leaves are passed; this is the $\frac{3}{8}$ rhythm, and it sings: 3, 3, 2; perpetually.

There is a whole series of these simple rhythms all built up with threes and twos and having this very curious and remarkable feature: that any two of the series, if added together, will make the next in order. Thus, if we add the numerators and denominators of the $\frac{2}{5}$ and $\frac{3}{8}$ we shall get the $\frac{5}{13}$ which is the rhythm of the golden-rod, amongst other plants, whose coil passes by thirteen leaves in five turns, singing 3, 3, 2; 3, 2. At the fourteenth leaf it finds itself just over the leaf it started with and begins again. If you add the numerators and denominators of $\frac{3}{8}$ and $\frac{5}{13}$ you get

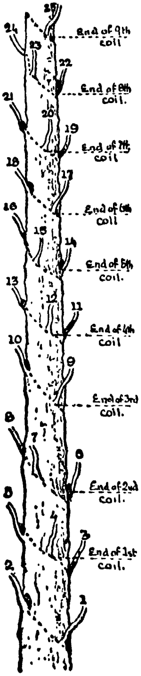
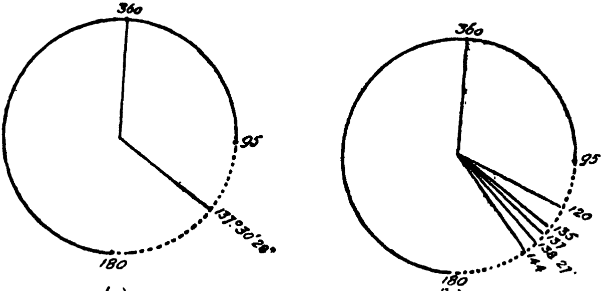


FIG. 8—Holly stem with leaves cut off, to shew the $\frac{3}{8}$ rhythm.

$\frac{8}{21}$, and here we have the complicated rhythm of the cone, whose coil passes by 21 scales in 8 turns singing 3, 3, 2; 3, 3, 2; 3, 2; before it finds one scale just over the first. If you have been able to mark a fir-cone as suggested in the last chapter you will find on examination that the scales in a direct line above the one you marked 1, will bear the numbers 22, 43, 64, 85, and so on, shewing that in each case 21 scales had to be passed by the coil before one was found exactly above the first. If you could procure the branch of a common araucaria (or monkey-puzzle) and, undeterred by its sharp spears which I know by experience can wound unpleasantly, would examine it carefully, you would find a similar arrangement to that of the cone of the spruce fir which we have examined. Eight spirals run one way and five the other, and the sequence is the same—an $\frac{8}{21}$ rhythm and the 22nd leaf just over the first. As the araucaria has green leaves instead of scales, and they are visibly planted on a round central axis and more spaced than the crowded fir-cone, it is very useful to compare the two if you get the chance, and it makes the facts that we were able to deduce as to the fir-cone's formation much clearer to the eye. Also, as the branch may go on for yards with the same sized leaves we can, if we wish, follow the sequence for a long distance and see that it still holds good.

The series of numbers which we have now brought to light are the so-called phyllotaxian numbers or those of the order of leaf-arrangement. They run as follows: $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, and so on, the numerator always giving the number of complete turns in our imaginary coil and the denominator the number of leaves it will pass in that number of turns before reaching a leaf in a direct line above the one with which it began. Thus in grasses the leaves are placed alternately on each side of the stalk and the coil will pass two leaves in every turn, the rhythm being 2, 2, 2, always. In certain sedges the coil in *every* complete turn will pass three leaves, returning then to begin a fresh coil exactly above the first leaf; this is the $\frac{1}{3}$ arrangement playing a simple 3, 3, 3, all the time; the rose (with many others) in two coils passes five leaves, playing 3, 2; the wallflower, holly, and many others pass in three coils eight leaves, playing 3, 3, 2; the golden-rod, common yarrow, and many others, in five coils pass thirteen leaves, playing 3, 3, 2; 3, 2; and the spruce fir-cone, araucaria, and others in eight coils pass 21 scales or leaves playing 3, 3, 2; 3, 3, 2; 3, 2. This series of course may continue indefinitely, but its characteristics will remain the same, the new numbers being always found to be the sum of the two previous ones.

All this hidden order and sequence amongst the leaves which look so irresponsible and careless is very surprising, but one must lay some stress on the fact that it *is* for the most part hidden, and that we must not expect to find these spiral rhythms clearly defined and readable on every shoot and branch. A thousand things interfere to mask their existence: leaf buds fail to develop, growth in the internodes (or parts of the stem between the leaves) may be arrested and leaves consequently be crowded together, trailing branches may have their leaves drawn into positions where they get the most sun and air. In fact, the Life-Force will not bind to an outward observance of law, but seems often to suffer that a plant seek its own best



(a) (b)

FIG. 9—The Ideal Angle.

(*a*) The "Ideal Angle," representing the angle of divergence of leaf from leaf, which, if repeated continually around the stem, would ensure that no leaf should ever come exactly over another, however long the spiral might be.

(*b*) The actual angles of divergence of leaves in the various phyllotaxian series shewing how nearly they approximate to the ideal angle. It will be seen that the "angle of divergence" implies the distance between one leaf and the next as regards the circumference of the stem. Thus if one leaf is placed at 144° the next will come at 288° and so on.

advantage in apparent forgetfulness. Yet if we go deeper and further into the subject I think we shall find that, though often masked, the rhythm is still latent within the being of the plant and may be discovered or may come to the surface in unexpected ways.

Let us clearly recognise that the growing point where the arrangement of the leaf buds is being laid down, is the tip of the shoot. Upon this fountain of life whence all is ceaselessly proceeding, the attention of mathematicians and botanists has been strongly centred. As we noticed in passing, it has been generally thought that the 'object' of the spiral arrangement of leaves on the stem was to obtain all the sunlight and air possible for each leaf by avoiding the placing of one leaf over another. Mathematicians tell us that the ideal angle of the divergence of leaf from leaf round a central axis would be 137° 30′ 28″ or approximately this, so that if every leaf were exactly placed at this angle of divergence from the next the spiral would continue for ever without one leaf ever being exactly over another; in short, we should have a perfect spiral ascending without pause or break.

Now quoting from Asa Gray's *Structural Botany* I find that the angles of the divergence of leaf from leaf in the series of phyllotaxian numbers that we have considered, are as follows:

In the $\frac{1}{2}$	arrangement	180°
In the $\frac{1}{3}$	,,	120°
In the $\frac{2}{5}$	,,	144°
In the $\frac{3}{8}$	,,	135°
In the $\frac{5}{13}$	,,	138° 27′ 41.54″
In the $\frac{8}{21}$	,,	137° 8′ 34.29″

From these figures one sees that the plant inspired by the Life-Force appears to be groping around that ideal angle as if trying to fix upon it. But a very remarkable thing is that in the apex of the leaf shoot where the beginnings of the new leaves arise, the angle of divergence at which they are placed is far nearer to the ideal than is shewn by the order which they subsequently follow. Thus Mr Cook tells us that in a plant which is building the $\frac{2}{5}$ system "the angle between successive primordia" (or developing leaf buds) "is nothing like the 144° postulated, but is very approximately 137°," that is only about half a minute different from the ideal angle. Thus we see that *in their origin* these varying rhythms of the plants are almost identical (for you will remember that the angle of divergence in the fir-cone is 137° 8′ approximately), and it seems as if the aim taken by the plant at the ideal angle were at that point wonderfully true, though later on varying, on this side of the mark and on that, in the different species. Again it is brought home to us that it is just these variations from the mathematically exact which give the charm and beauty to Nature and are apparently inherent in her life. Neither botanist nor mathematician has been able to suggest a final cause for these spiral rhythms nor to explain how they arise. One suggestion, however, has been made by the late Chauncey Wright as regards the latter point, which appears to me very illuminating. According to his supposition, an early form of leafage may have consisted in a continuous spiral leaf-like frond winding its way up the axis like a spiral stairway; in later developments this may have become separated into segments which of course would follow the same spiral course. At first sight this appears very fanciful, but I have been much struck by finding illustrations of two plants, one a seaweed, Vidalia volubilis, and one amongst mosses and liverworts, Riella helicophylla, in which exactly this continuous "staircase-like frill" is realized. Mr Cook, who reproduces these illustrations from a Flora of Algeria (1848), remarks that "suggestions of a similar formation are to be found even amongst higher plants." It thus appears as if it might be a perfectly possible explanation of the way in which the spiral form began, though of course the *cause* is a far deeper matter, and must be of universal and not partial application.

If, as I cannot help hoping, some of those who have cared to follow me in this rather technical chapter so far have been instigated to make some search for themselves amongst the plants that happen to be available, in order to try to verify these rhythmic spirals for themselves, they are sure, amongst many other baffling and disturbing facts, to come across numbers of plants bearing their leaves either in pairs or in whorls instead of alternately in an ascending line up the stem. What becomes of the spiral here? one naturally asks. And if, as some botanists are inclined to say, "whorls and spirals . . . are to be considered . . . as distinct modes, not to be practically homologized into one" (Asa Gray) I confess I should feel this a great shock to my sense of the unity and continuity of Nature. But even Asa Gray is evidently half-hearted in the above pronouncement, for he continues: "Nevertheless transitions between the two and abrupt changes from one to the other on the same axis are not uncommon. . . . If the spiral be assumed as the fundamental order, it is not difficult to form a clear conception as to how such changes come to pass." He then goes on to shew that a single whorl of, say, five leaves can very easily be understood to be caused by the non-development of the internodes (or spaces between the leaves) in a single beat of the $\frac{2}{5}$ rhythm (3, 2;). But the next whorl instead of beginning exactly over the first (as it ought to do if we are to be saved all disturbance of mind!) puts its leaves so as to stand *between* those of the previous one. Asa Gray here remarks: "We cannot homologize this with spiral phyllotaxy; for in this lies the fundamental difference between the two plans." He then makes an attempt to form some idea as to the origin of both forms by imagining that as the ordinary spiral may have arisen from the continuous winding leafy wing starting on one side of the stem of which we spoke before, so the circle or whorl may have originated in a *double* leafage of the same kind. In his own words: "the frond of Fucaceous Algæ, Hepaticæ, and the like, is two-bladed. While a one-bladed frond, or with one blade suppressed, might be the original of alternate leaved spirals, the two-bladed frond, similarly broken up, would give rise to the opposite or other varieties of the verticillate" (whorled) "arrangement." This again, apparently is a conception of Chauncey

Wright, and at all events it leaves us with some sort of notion of unity at the root of the two modes.

But on this point I have my own little story to tell of thought and observation and a long course of work. It seemed to me when I began it that very much hung upon it, and that if I could not find the spiral in the whorl I was ' lost ', so to speak, and my view of the unity of Nature was all broken up! So foolish we are! and so persistently do we endeavour to make our secondary spirals take in every scale of our fir-cone! However, a good deal came to light in the course of my investigations, and I think it may be worth while to set down here, as clearly as I can, what I did find, and what seemed to be the results of my search. Those of my readers who are not specially interested can easily miss the rest of this chapter and pass on to less technical subjects.

A whorl of leaves, we must take it, represents an economy of growing power in the plant. Instead of each leaf being separated vertically from its neighbour by a little piece of stem, two, three, or more leaves are produced all together in a circle. They are arranged at regular intervals round the stem, but there is nothing to shew what is their proper order; which comes first, second and third and so on. If we can discover this we may be able to make out how the rhythm is running, and whether the phyllotaxian numbers are still to be found. It was whilst I was trying to investigate this matter that I came by chance upon a plant which was almost as good as a vocabulary to a person studying a foreign language. The plant in question is Sedum spectabile—a pretty thing with pale grey-green juicy leaves and large flat heads of soft purplish-pink blossoms, greatly beloved of peacock butterflies.

This sedum grows its leaves in three different ways: sometimes it produces them in an ordinary spiral, sometimes they grow in pairs, and sometimes in threes. Here was my chance. By comparing specimens of each of these three modes I could see exactly how the spiral disposed itself to form pairs and triplets. In order to assist myself in this work I made diagrams of the stem and leaves in bird's-eye view with a circle for the stem and the leaves represented by strokes at the proper intervals round it. How often I used to wish that the leaves were movable and would slide up and down the stem at my convenience! It would have been an immense saving of labour! However, failing this thoughtful arrangement of Nature, the circles did useful work in enabling me to make observations and calculations which could not be worked out in short lengths such as the living shoot presented.

The ordinary spiral in this sedum is arranged on the $\frac{3}{8}$ plan, the coil traversing $\frac{3}{8}$ of the circumference of the stem between every two leaves. When it grows its leaves in pairs it has to make a slight modification of this plan, which, however, *gives the same result.* The two leaves in each pair stand exactly opposite to one another, and the pairs alternate in direction, so that if the first pair looks east and west, the next will look north and south. Following the coil carefully in this arrangement, I found that it moved half the circumference of the stem between the first two leaves and a quarter of the circumference between the next two, and so continued to move in regular alternation. This gives an average movement of $\frac{6}{8}$ for every two moves, and works out on the $\frac{3}{8}$ plan. The wheel of movement turns thus: east, west, north, south; west, east, south, north, and so on; and the 9th leaf (the first in the 5th pair) stands exactly above the first and begins a new cycle. You will probably say: "So does the 6th leaf in the third pair. Surely this is the $\frac{2}{5}$ arrangement." But a short examination will reveal the mistake, as the $\frac{2}{5}$ arrangement should bring the 11th and 16th leaves over the first, which does not occur here, and the reason is plain when we observe that the cycle is not complete at the 6th leaf, and the movement thence is not $\frac{1}{2}$ as at the beginning but $\frac{1}{4}$ (to

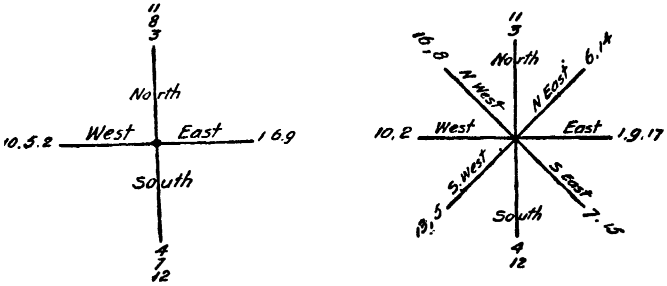


FIG. 10—Diagrams to shew the movement of the rhythm in alternate pairs of leaves and in alternate whorls of fours.

the south), being in the middle of its revolution. It will be seen that the mere fact of one leaf standing exactly over another does not by any means give a sure key to the situation. We have to ascertain the end of the complete cycle.

Before going on to the sedum's plan when growing its leaves in triplets, I want to make perfectly clear the points we have gained so far. If once it is granted that the phyllotaxian numbers are to be discovered in the case of alternating pairs, and that the spiral with one of the phyllotaxian series can be read in them, we have practically won the position, however difficult and complicated larger whorls may be to read, for pairs alternating in direction are always included by botanists with whorls, and indeed they are, as you will see, whorls of four. Now in the Sedum spectabile, *in spite of a change of the distance from leaf to leaf* as regards the circumference of the stem, the average works out the same, and the winding cotton will give the same rhythm as any other $\frac{3}{8}$ spiral, 3, 3, 2, the 9th leaf being over the first, when the next beat starts as before. The plant I have chosen as an example and guide is not a solitary case. I have the authority of the fuchsia that my system is so far correct. Like Sedum spectabile the fuchsia often places its leaves in pairs, alternating like the sedum, sometimes in whorls of *four*, alternating so that no leaf of the second whorl stands exactly over one in the previous whorl; sometimes in threes, and sometimes in a spiral. Strange to say its arrangement in the last-named form is generally the $\frac{2}{5}$ series.

One day I was lucky enough, however, to find a fuchsia with its leaves arranged up the stem in a spiral which, instead of following the ordinary $\frac{2}{5}$ plan, followed exactly my diagram for alternate pairs, and ran east, west, north, south; west east, south, north, singing 3, 3, 2 as merrily as one could wish! This of course was a great encouragement to me for it certainly seemed to shew that my reading of the rhythm of its alternating pairs was correct.

I now went on to study the arrangement of alternating whorls of four in the fuchsia, before considering the triplets in this plant and Sedum spectabile. Alternating fours, of course, represent whorls of eight. I found that the wheel of movement ran as follows: east, west, north, south; south-west, north-east; south-east, north-west; and then *da capo*.[1] The rhythm shewn by the coiling cotton will still be the $\frac{3}{8}$ with its 3, 3, 2. But there is a very strange and remarkable thing about the placing of the leaves as regards their distance one from another in relation to the circumference of the stem. In the alternate pairs we found this to be $\frac{1}{2}$ and $\frac{1}{4}$ alternately; but in the alternate fours a further modification takes place, and the distances run as follows: $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{1}{8}$, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{8}$. Thus the plant, having had to reduce the space between the last leaf of the first whorl of four and the first leaf of the second whorl, makes up by *increasing* the space between the last leaf of the second whorl of four and the first leaf of the third whorl, which is the ninth leaf and begins the next cycle. The rhythm runs as before: 3, 3, 2. We have here, as you see, worked out the rhythm of a whorl of 8, and in passing to the case of alternating triplets we come to whorls of 6.

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[1] See figure 10.

When Sedum spectabile or the fuchsia grow their leaves in alternating triplets, a considerable modification of the rhythm takes place. In the case of the pairs of leaves alternating we found that they still swung round to the 3, 3, 2 rhythm as does the $\frac{3}{8}$ spiral, but now there is a change. The $\frac{3}{8}$ distance changes to $\frac{2}{6}$. When three leaves have been so placed, the fourth leaf has to be planted a little further round to avoid growing exactly over No. 1, in which case the two sets of three would stand exactly over one another and the effect would be to shut off light and air from the lower ones. The fourth leaf therefore of the triplets is placed at an interval of $\frac{3}{6}$ to fall between No. 1 and No. 2. To compensate for this extra $\frac{1}{6}$ there is a corresponding reduction of space between the last leaf of the whorl of six and the first leaf of the next whorl, and the seventh leaf is only $\frac{1}{6}$ from the sixth leaf. Thus the movement runs: $\frac{2}{6}$, $\frac{2}{6}$, $\frac{3}{6}$; $\frac{2}{6}$, $\frac{2}{6}$, $\frac{1}{6}$, and the rhythm is the $\frac{1}{3}$ series playing 3, 3, 3, like the sedge.

Now, indeed, we seem to be faced with a very serious difficulty, which at first sight is quite baffling. Here is the fuchsia playing $\frac{2}{5}$ as an ordinary spiral with its leaves, $\frac{3}{8}$ with its alternating pairs, and also with its whorls of four, $\frac{3}{8}$ also with the parts of its flower which are really modified leaves, and finally $\frac{1}{3}$ with its occasional triplets! What can we make of this?

It is by no means alone either in its extraordinarily inconsequent behaviour as we shall find if we make a short investigation.

Let us always remember that the parts of the flower are really modified leaves and that what is true of the leaf is true also of the flower, so that we shall expect to find the phyllotaxian numbers in the arrangement of sepals, petals, stamens, and carpels (or division of the seed capsule). Sedum spectabile, playing a $\frac{3}{8}$ rhythm with its ordinary spiral and in its alternating pairs of leaves, has also these embarrassing triplets, and moreover when it comes to flowering

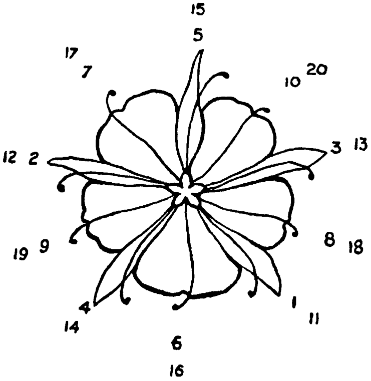

FIG. 11—Diagram of flower with its parts in fives, to shew the order of their placing. In two turns of the coil the five sepals are placed; in two more the five petals, and the first stamen comes over the first sepal, when the same order is observed in the placing of the remaining stamens.

time it follows the $\frac{2}{5}$ rhythm in the following manner: It has five sepals, five petals, ten stamens, and five carpels. The sepals and petals alternate in position and the stamens do likewise; so we have to do here with whorls of ten. The distance traversed by the coil between the leaves when placing five around the stem is $\frac{2}{5}$ as we saw; and when ten leaves are to be placed, the same distance ($\frac{2}{5}$ or $\frac{4}{10}$) is observed till five leaves are placed; then—just as we saw in the whorl of six—a modification takes place, and $\frac{5}{10}$ are traversed, dropping the sixth leaf between Nos. 1 and 4. When the whole ten of a whorl are planted, the next whorl starts from a point above No. 1, only $\frac{3}{10}$ being crossed in the last move. So the movement runs: $\frac{4}{10}$, $\frac{4}{10}$, $\frac{4}{10}$, $\frac{4}{10}$, $\frac{5}{10}$; $\frac{4}{10}$, $\frac{4}{10}$, $\frac{4}{10}$, $\frac{4}{10}$, $\frac{3}{10}$; the $\frac{1}{10}$ too much in the first part being equalized by the $\frac{1}{10}$ too little in the second part, and the whole therefore working out on the $\frac{2}{5}$ plan and having a rhythm of 3, 2; 3, 2.

What has to be accounted for, then, is the playing of a number of different rhythms—all within the phyllotaxian series—by the same plant at certain stages of its growth and development. If these varying rhythms only appeared in my reading of the whorls it would certainly be a grave question whether I was justified in believing that I had found the phyllotaxian spirality in the latter. But if the diversity appears likewise in the spirals of leaf arrangement, there must be some underlying cause, and my argument for the unity of spirals and whorls is not vitiated.

Let us take the case of the Rose-bay willow herb—a plant on which I made some careful studies. The spiral seems to be normally the $\frac{5}{13}$ arrangement with a rhythm of 3, 3, 2; 3, 2, but the individual plants are extremely variable, and in my notes with many diagrams from living specimens I find the remark: "I have found specimens shewing the $\frac{3}{8}$ series quite definitely, also some apparently having the $\frac{2}{5}$, and it really seems as if any of the three might be produced in this plant." I may remark that the flower of this willow herb has four sepals, four petals, and eight stamens, and is evidently on the $\frac{3}{8}$ plan. The same tendency to vary from their ordinary rhythm may be often noted in the holly, laurel, and many other plants, and one is driven to the conclusion that there is a natural liability to variation in the rhythm of many plants, always within the phyllotaxian numbers and always building in obedience to its laws in threes and twos, never more than two threes consecutively, nor more than one two, except of course in the $\frac{1}{2}$ or $\frac{1}{3}$ rhythm where only repeated twos or threes respectively compose the arrangement. Nor need we wonder so much, or find it so hard to explain this variation of the rhythms played by the leaves in varying circumstances, when we consider what we have been told as to the angle of divergence of leaves at the tip of the shoot where the new leaves are appearing. Remember that we were assured that the aim of the plant at the ideal angle was far more exact there than in the ultimate arrangement of the leaves, and practically that the varying numbers of the phyllotaxian series which, later, developed in different plants, were but these plants' individual responses to the life-call, at the growing point, to approximate to the ideal angle. Now what more natural than that at some point of growth the response should be closer than at others, and a higher order in the ascending series should be reached?

I find a striking confirmation of my own observations and suppositions in a remark made by Asa Gray in his *Structural Botany.* He is describing the parts of flowers with relation to phyllotaxy, and in this connection has remarked: "the parts of the flower are arranged on the receptacle as leaves are arranged on the stem; i.e. they conform to phyllotaxy as well in passing from leaves and bracts" (the generally more or less changed leaves just beneath the flower or within the flower-cluster) "to the perianth, as in the position of the floral organs in respect to each other. . . . Sepals, petals, stamens, and pistils are either in whorls or in spirals, and have nothing in their arrangements as to position which is not paralleled in the foliage." Further on he explains that the parts of flowers, like leaves, are sometimes (though rather less commonly) in spirals, and sometimes in whorls, and are to be taken as analogous in every way as regards phyllotaxy.

Now comes the passage confirming my observation as to the variation in rhythm which may take place in the spirals of leaves in certain plants: "The flower of Camellia" he writes "is continuously on the spiral plan up to the gynœcium" (pistil with its carpels) "but upon one which, from the bracts onward, *rises from the* $\frac{1}{2}$ *to the* $\frac{2}{5}$ *and* $\frac{3}{8}$ *order or higher*" (meaning that these varying rhythms are found side by side) "throwing the petals of the rosette in a full-double flower into numerous more or less conspicuous vertical ranks."

It would be easy to strengthen my case by giving further definite examples of variability in the rhythm of leaf or flower spirals on the same plant, but I am anxious not to weary my readers, and I think it is now plain that we must not be surprised at such occurrences, but recognize that they may be explained by the searching of the individual plant under the influence of the Life-Force after the ideal angle, or—having practically attained it—the failure temporarily to hold to it. I have often observed that the strongest and best-grown shoots in a plant are those that are most faithful to their own rhythm, and it is the less fortunate ones generally which fall back to a lower one.

In the cases where the flower rhythm is different from the leaf rhythm of a plant, this is very often to be explained by the fact of the flowers in question having ceased to grow so many parts as they properly ought to have, and used to have originally. This may seem very odd, and why they should become so parsimonious and try to "make do" with fewer is not always very clear, but it is a well-known fact and easily proved. The common barberry plays the $\frac{3}{8}$ rhythm with its leaves, but when it comes to flowering has normally 6 sepals, 6 petals, and 12 stamens. However, I have found quite a number of flowers on my barberry bush with 8 sepals, 8 petals, and 16 stamens, which would of course fall into the $\frac{3}{8}$ rhythm. I have no doubt that the barberry used to grow its flowers thus, but has economized some of its parts and grown into this habit. Again, the relations of the fuchsia are all $\frac{3}{8}$ rhythmed folk and its $\frac{2}{5}$ leafage seems to be an innovation in the family. Often there is an *increase* in the original number of parts in a flower and again the rhythm becomes altered. It is unnecessary to go into this large subject further. My point in this discussion has been that the fact that the rhythm discoverable in whorls of leaves or whorled flowers is not always the same as that played by the leafage of the same plant is not to be taken as any argument against the view that whorls and spirals are one and the same in origin. Of course all that I say here is tentative, but I think it has been made clear that the rhythm of the phyllotaxian numbers is to be read both in the opposite-leafed arrangement and in whorls, though, I admit, with a change in the distances between the leaves as regards the circumference of the stem. These distances, however, *average* the correct divergence and the rhythm is there though the arrangement masks it. Spirals and whorls are constantly to be found alternating on the same plant, and if I deduce from my examination of the latter that the spiral is there though masked or hidden, am I more imaginative than the geologist who,

seeing an outcrop of a certain rock which disappears, giving place to an indeterminate strata, and reappears further on, infers from this that the rock underlies the whole and is masked for the time by the covering layer? Again, if I find an ancient writing of which some part is clearly to be read and understood, and if this is followed by a part making apparent nonsense, but by the orderly transposition of certain letters I find I can read it so as to make sense and to agree with what goes before, am I not justified in supposing that I have found the right clue?

The ways of Nature are most difficult to follow and life claims a freedom of her own to hide the law which lies at her heart, but I think we have seen enough to enable us to recognize, as Theodore Cook puts it in the passage quoted early in the first chapter of this book, "in nearly all the apparently fantastic irregularities" of the world of plant life, those same "laws of spirality" which he traced and acknowledged in the heavenly bodies.

CHAPTER III

ADAPTABILITY IN PLANT LIFE

(*Meeting a difficult situation.*)

THOUGH I hope that some of my readers have cared to follow me patiently through the discussion in the last chapter, and that I have not been talking to myself with no one to listen, yet I am quite aware that to many people the strings of figures and details of rhythms and movement will seem invincibly dull and unattractive. For the few who could be interested, I have set down the results of my own researches for what they are worth, mainly with the hope that some may be tempted to go straight to Nature and ask her if these things are so! For I am convinced that a genuine search after truth is always rewarded, and that, whatever mistakes we make, there is no better school for anyone who has to live on this particular globe of ours, with the particular kind of Life-Force working throughout its inhabitants, than the study of this Life-Force at first-hand with a patient determination to grasp something, at least, of its character and laws.

One of the first things that strike one, directly one begins this sort of study, is the exuberance of idea and of resource which result from the working of the Life-Force. Nothing goes on in a dull routine, everything is changing and moving, though in most cases so slowly as not to be obvious to the casual glance. We have seen the tendency to vary in the plant's response to the Life-Force, and through this tendency, which seems inherent, though there is mystery in its cause and meaning, all sorts of small changes arise, and if they help the plant in any way they are likely to be perpetuated by natural selection, and so an extraordinary variety of 'adaptations' and 'devices' come about, which have been described by Darwin and those who followed him with great minuteness and care.

At one time natural selection was supposed to be a key that would unlock every door and throw open every apparent mystery. Going hand in hand with adaptation and environment, it does seem to account for most things. But occasionally one gets a shock, which makes one doubt if this is really all there is to be said. And I think many scientists feel that, great as was the illumination of Darwin's theories, the truth he brought to light does not cover all the field.

Someone has remarked that as regards adaptation and environment, nothing could be more perfect than that of one of the lower parasites, nourished by the blood of its host and in every way completely adapted to its way of life! Yet instinctively one feels that this could scarcely be the ideal towards which the Life-Force is urging! One is almost driven to the idea of some kind of *choice* in the obedience of plants to the life that inspires them, and that a lower choice involves a downward road. That I am not alone in these imaginings was proved to me by the following passages in Professor J. Y. Simpson's *Man and the Attainment of Immortality:* " Complete adaptation to the proximate material aspect has always meant stagnation and destruction, sooner or later." And further on he says: " The winning of freedom, however, leaves the way open, as we have seen, for the introduction of wrong methods in the lower creation." And again: " If growing freedom has been used in many cases to escape from the pressure, to get out of the narrow, upward way that was to lead to man, by complete adaptation to some trivial or temporary aspect, as in parasitism or some other way, such a state of static equilibrium has always in the end meant stagnation and degeneration for the forms in question. At every stage there have been these varied types of response to the stimulating, beckoning environment; throughout, it is only by ' a very small remnant ' that the advance has been maintained. . . . Other forms have settled down in an equilibrium of complete adaptation to some immediate aspect of the environment. It has always been the easy thing to do. But such over-specialization on their part has inevitably spelled their evolutionary doom."

Dr J. E. Taylor, writing as long ago as 1884, says: "The near future may have occasion to shew there can be no life absolutely without *psychological* action—that the latter is the result of the former. It may some day be shown that life is conditioned by psychological action: and that there is in plants the equivalent of 'instinct' in animals—the power of gaining individual experience, and of transferring such experience to descendants to profit thereby, not altogether unconsciously." As he rightly says further on: "Responsibility is another matter. It can only be attained when consciousness and volition have reached a certain stage of development," but he boldly postulates a possible 'instinct' in plants which may involve some kind of consciousness.

With these thoughts in our minds it may be interesting to follow the roads taken by certain groups of plants in their special responses to the urge of the Life-Force within them.

Before we enter on these paths, however, it is necessary to understand clearly the normal parts and organs of a present-day fully developed plant, and their special work. These of course have arisen through the ceaseless working of the same Life-Force, from the little one-celled organisms in which both animal and vegetable—almost indistinguishable in that stage—took their beginning. But the story of that gradual evolution has been told again and again by the best and most graphic writers, and everybody knows something of it. Grant Allen, has described for us in the most vivid and interesting way the origin and development of flowers in what was once a green flowerless world, and how the various insects, as they came into being in that ancient world through the same gradual processes of evolution, became the winged love-messengers from flower to flower to carry the pollen from one to the pistil of another and so to perform the most important office of cross-fertilization for the benefit of the race: how these coveted messengers, searching for honey and pollen, were attracted by varying colours, arising fortuitously, at first, and so the plants learned to hang out varying signals, first golden yellow, then white; later on pink, red, purple, and last of all the royal blue, said to be best beloved by bees, to attract these messengers of blessing; and so insects and flowers, developing hand in hand, produced the world as we know it, brilliant with colour and beauty, bright with jewelled butterflies, murmurous with the hum of bees, and fragrant with the scent of blossom. All this fascinating story can be best read in some of Grant Allen's popular works. I once tried to tell it after him in some small way in a book called *The Making of a Daisy* written some years ago. But, leaving the past, let us take things as we find them in the present stage of development and see what roads have been taken by the various groups of plants and how they are faring.

A normal plant of the present day possesses certain necessary organs, as do our own bodies. The equipment of a typical flowering plant of the higher grade is generally speaking as follows:

(1) A root wherewith to draw nourishment from the earth, and to act as an anchor: (2) A stem whereby to lift itself to the light and air and to act as a support for its further appendages: (3) Leaves wherein to prepare the raw elements drawn from the earth by the roots, and to render them fit for assimilation by the plant: (This is done by the green chlorophyll granules in the cells of the leaves.) (4) Organs of reproduction, which are really modified leaves, changed to do a new work. These consist of stamens, bearing pollen grains, and a pistil containing ovules: (I mention these first because they almost certainly arose first, and were formed out of modified leaves.) A calyx for protection of the floral organs, consisting of (generally green)

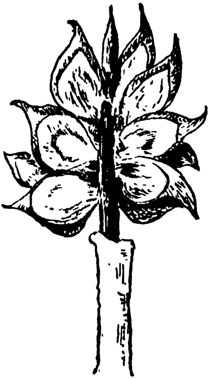

FIG. 12—Head of Buttercup Fruit
(Cut in half in order to shew carpels better.)
"Fruits" all separate and each with one little ovule in the "nursery".

"sepals", and a corolla of (generally) coloured petals for the attraction of insects. A typical plant is the common field buttercup which has all these parts clearly to be distinguished, and the parts of its flower separate from one another and simple in form. The common geranium, if easier to obtain, will answer our purpose almost as well. Every one of the organs of such a typical plant is liable to change and modification in the course of gradual evolution, and the more changes we find from such a simple form

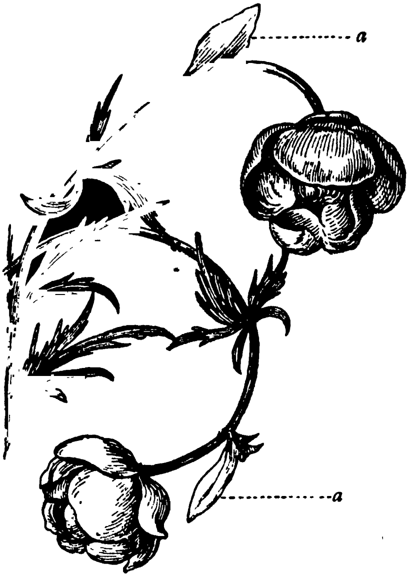

FIG. 13—Trollius with green sepals and bracts changed to bright yellow petals. One leaf can be seen actually partly green and partly changed to petal-like colour and form, *a. a.*

as that of a buttercup, the greater, we know, has been the response to the urge of the Life-Force pressing it on to adapt itself to the conditions of its environment. Bracts (the small, often colourless leaves generally found close under the flowers) and sepals of the calyx may take on wonderful colours to attract insects, as in the little milkwort which jewels our downland; stems may flatten out and do duty for leaves as in a leafless form of broom, a native of Switzerland, called Genista Sagittalis, or in the rare English Butcher's broom with its stiff leaf-like branches which deceivè the casual

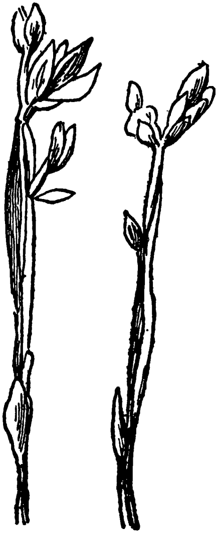

FIG. 14—Genista Sagittalis with flattened stems to do duty as leaves.

observer into the belief that they are true leaves until, to his amazement, he sees the wee flowers growing on their face. Petals may become united into bells as in the harebell, or may take on wonderful forms, and in some cases imitations of the insects they wish to attract, as in the fly orchis—to my mind more perfect and beautiful even than the better-known bee orchis—which is one of the most highly developed of our native flowers, and is as perfect a model of a fly as you could wish to see. Stamens may be united in bundles as in the pea flower,

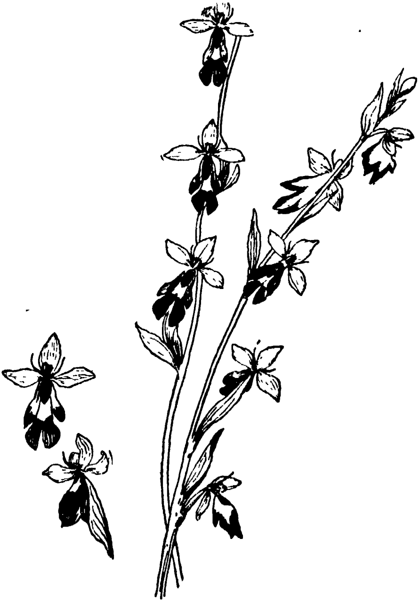

FIG. 15—Fly orchis.

or they may attach themselves to the petals as in the barberry. Pistils may unite the cells of their ovary into one large seed-vessel with separate compartments as in the evening primrose or poppy.

Pages might be filled with the almost infinite changes which are found to have taken place in the forms of flowers in the course of their slow development. Of changes of colour we have already spoken, and it must be remembered that when we find lines and markings, blotches and patterns upon the blossoms, or when two or three colours are united, as in the case of the pansy and the sweet pea, we are usually dealing with highly developed species. The number of parts varies enormously, and changes in these are very common.

There are two great divisions in flowering plants, the Monocotyledons (having one seed leaf) and the Dicotyledons (having two seed leaves), and the typical numbers for these two divisions are threes or multiples of three for the Monocotyledons, which include the orchises, all lilies, grasses, rushes, etc. etc., and fours or fives, or multiples of these for the Dicotyledons, which is the larger and more varied class. Changes in these typical numbers arise from suppression of parts, as I remarked in the last chapter with regard to the barberry, or in increase of normal parts, as in "double" flowers. These hints may enable anyone to form a guess as to the position of any plant in the scale of evolution—that is, in response to the working of the Life-Force.

Now I propose to gather one or two plants from the fields, one from the woods, and one from a bog, and to compare these with the buttercup.

From our chalk pastures I gather the little eyebright (Euphrasia officinalis), common enough on dry meadows or on cliffs. It is a pretty little flower, with white-lipped petals, marked with lilac and a dash of yellow, less simple in form and more highly developed than the buttercup. Long before I knew that there was anything peculiar about it I used often to wonder at this little plant, to think how unlike its rather stiff, purplish foliage was to that of the ordinary little green plants of the meadow, and to be surprised that when I tried to pick it, the whole plant usually came up in my hand, and the root seemed to be almost without the usual little fibres which go searching for food in the ground in the case of the buttercup, and at the same time anchor the whole plant firmly, so that it requires a hard pull and some care to get it up intact. The red bartsia (Bartsia odontites) has the same characteristics and may be easier to obtain. It is common in corn-fields and dry fields. Anne Pratt describes it rather well: " it is a much-branched herbaceous plant " she says, " with a slender stem about a foot high, and numerous spikes of dull pink flowers, having the floral leaves of a dim pinkish brown. The hue of these leaves, of the calyx, flowers, and stem, is in some specimens pretty nearly uniform, and of dull red, and the plant rarely exhibits any brightness of colour." She tells us that cattle will not eat it and are said to leave the grass untouched around it. This plant, too, used to awaken a vague wonder in my mind, and a sense of something wanting—something less alive than it should be—but still I knew not what it was.

In the dry birch woods in the mountainous parts of Scotland, where few other flowers grow, I have found often the yellow lesser-flowered cow-wheat; and its commoner larger flowered brother (Melampyrum pratense) is very frequent in fir and birch woods and thickets. The plant has a straggling, slender stem and the flowers are pale yellow, sometimes cream-coloured, and all turning the same way on the stem. The leaves are narrow and tapering, of a rather dark green. This is the third flower of my curious bouquet, and in it also there is the same indefinable want, the same failure to appeal to that within us which responds to life.

Finally, out of the bog or marshy land in almost any part of England, we will gather the lousewort—sometimes more prettily named the red-rattle—with its red flowers, lipped like a hemp nettle, and its deeply-cut purplish foliage. It has a brother of the damp pastures, very much like itself, but paler in colour and sometimes white. These are perhaps the most attractive flowers of our nosegay, but looking at the root we shall notice the same absence of fine fibres, the stem ending in three or four rather stiff little rootlets, which have the appearance of being broken at the ends. It was only, I think, in 1847 that light was first thrown on the real history of these and a few other similar plants. Monsieur Decaisne published in that year in the *Comptes Rendus* his explanation of the fact which had been observed that the yellow-rattle (a near relation of the lousewort) when growing in the pasture injured, or as the farmers said, "burned" the grass. M. Decaisne discovered that the injury was done by the fact that the yellow-rattle was actually *parasitic* upon the roots of the grass, and drew its nourishment from their life. Experiments were made, and Professor Henslow found that the plants of the rattle when growing by themselves did not thrive, seldom flowered, and did not set seed. It was afterwards discovered that many plants of the same family (for all those in our bouquet belong to the tribe or family of the Scrophulariaceæ) had adopted the same pernicious habit and instead of working honestly with their roots like the buttercup, as a plant should do, were pilfering from their neighbours underground, and sucking their life-blood whilst appearing outwardly .to lead a normal, healthy life! Before this, it had been believed that the well-known mistletoe was the only green parasite of our islands, and these little underground blood-suckers had never been suspected. Yet, as I have shewn, I think their appearance hinted at something wrong with them, and it certainly gave me a cold feeling before I had a suspicion of the reason!

Besides these that I have mentioned, I think there is only one more green English plant parasitic on roots, and this is an unattractive little green-flowered plant of dry chalky pastures called bastard toad-flax (Thesium linophyllum) the only English species of its tribe.

Probably you will have noticed that most of these plants grow in dry places where nourishment cannot be very abundant, and in spite of the plentiful water-supply in a bog or marsh I think that there also, there is a shortage of important plant foods, and we shall find that another little denizen of the bog has resorted to a still more unusual expedient to supply its wants. It seems to me probable that these green parasites, all of which are rather highly developed plants and have gone a long way up the scale of evolution, were originally as honest as the little blue-eyed speedwell, who is their near relation, and indeed some of them do not appear even now to be completely committed to their parasitic existence, as apparently the yellow-rattle can sometimes carry on a pinched existence on its own roots. Moreover, they still have some green chlorophyll in the cells of their leaves, and this means that they can still prepare for themselves the crude sap which is what they steal from the roots of other plants. It is the special property of green plants to use the constituents of the mineral world drawn up in liquid form by their roots wherewith to build their bodies; but they cannot assimilate this material without preparation any more than the animal can, and it is the chlorophyll granules within the cells of their green parts which do this work. Parasites which have not lost their green colour still have this very precious power, though they are certainly on the way to lose it, and one cannot but feel that they have already *chosen* at a critical point and chosen the downward path, and that some life has ebbed accordingly.

Further on down this same path of adaptation to difficult circumstances which yet is surely not the true response to the urge of the Life-Force, we come to the true parasites, openly dependent upon their 'host' for nurture. Many of these have attached themselves to a special kind of plant as host and will not have any other, and one can imagine how this restricts their chance of life. The tooth-wort (Lathræa squamaria), for instance, is said by Sir J. D. Hooker to prefer the hazel for its host, though it has also been found on the roots of elms. It has a fleshy stem like a fungus, is entirely without leaves, having only pale colourless bracts beneath its shadowy flowers which are all on one side of the stem, and it rather shuns the light, preferring to grow in shady recesses of the wood. One is not surprised to find that it is a rather rare plant. The broom-rapes belong to the same category and are of the same tribe. Most of the tribe seem to be rare, and some extremely so, and it is evident enough that their way of living is not conducive to the eventual perpetuation of their species. Like the tooth-wort they are entirely leafless, with succulent stems forming spikes of dull brown, yellow, or purple flowers, very clammy to the touch. They have something of the appearance of the orchis to the casual glance. Anne Pratt, who generally has something of interest to tell us, says that it is difficult to distinguish one species from another because parasitic plants "become much altered by the substance of plants on which they feed, so that it requires much attention to ascertain how far any distinctions are permanent." Each species, she remarks, prefers its own peculiar aliment. She tells us that "it has been proved by experiments that their seeds will lie dormant in the soil for years until the plant to which the species attaches itself shoots out its roots near them, when they immediately seize upon them, often to the very great detriment of the foster-plant." Both broom-rapes and tooth-wort have a certain beauty of their own, as well as their curious appearance, so that some have desired to grow them in their gardens, and in spite of the obvious difficulty success has been obtained in several cases by those having an intimate knowledge of the requirements of the plants.

A Mr Dovaston, who after four or five years succeeded in persuading tooth-wort to grow on the roots of the hazel, says: "it will . . . turn pink or purple when very much exposed to the light; for having cut away some of the hazel branches to bring it more in view . . . the sunbeams in a few days turned it so very pinky and purple, that some . . . were very much struck with the beauty and delicacy of the colours, though the plant itself is rather of a repulsive and cadaverous aspect."

Since these leafless parasites have no chlorophyll, it is obvious that they must abstract from their hosts not merely crude sap but the elaborated food prepared in the green leaves and distributed thence for the maintenance of the life of the plant.

The dodder, of which we have spoken earlier, is the last of these complete parasites to which I want to refer. Perhaps it will be remembered that in the first chapter of this book I spoke of the embryo of the dodder as a naked thread spirally coiled in the seed. ·These seeds germinate in the ground and a little thread-like plant emerges, which as Dr J. E. Taylor says: " looks or feels about for its victim, and dies down in a few days if it cannot find one." Like the broom-rapes, the dodders select each one or two special plants for their host and will grow on no other. Thus there is the clover-dodder, the flax-dodder, and several others which attach themselves to gorse, thyme, and a few other plants, mostly of the heathlands.

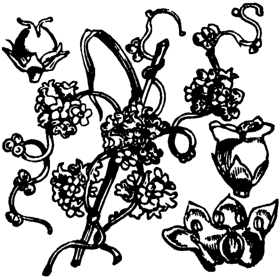

FIG. 16—The Dodder.

I well remember my first view of one of the last named (Cuscuta Epithymum) at Sheringham in Norfolk where it had tied up a gorse bush in a perfect tangle of red threads. I had never seen anything like it, and was utterly amazed, and hardly able to believe that the mass of ruddy hair, as it appeared to me, was a plant at all! Presently, I saw that it had little balls of pink, wax-like flowers at intervals, and really, its colouring in the sunshine was extraordinarily beautiful! But the poor gorse bush hadn't a chance and was bound hand and foot!

Dr J. E. Taylor tells us that as soon as its prey is found "the wire-like stem of the dodder takes one or two coils around the victim, and develops a series of sucker-like aerial roots which penetrate into its tissues to the up-flowing sap." After this "it lets go its hold upon the soil where it germinated, but not before." All this seems very bloodthirsty and deliberate in so delicate and fragile-looking a being!

But as the same author remarks, as though in extenuation: "the only cause assignable for the parasitism of these higher plants is poverty —which forces them to choose between parasitism and extinction."

Yet other ways have been found; and without pursuing this rather sad path of the degenerates further, or speaking of the Saprophites, like the bird's-nest orchis, which subsist on decaying vegetable matter, and are closer still to the fungus in appearance and nature, I will turn in the next chapter to a really delightful story of a means found by a whole family of plants of securing a splendid rich life in abject poverty of the soil!

CHAPTER IV

"A MORE EXCELLENT WAY"

MANY years ago a brother of mine in New Zealand was moved to wonder at a large quantity of yellow lupins which grew on pure sand with apparently no plant nourishment at all, and upon this wretched diet contrived to produce fat pods full of seeds rich in nitrogen. The same problem in various forms, but always amongst members of the pea and bean tribe of plants, had occupied many botanists. Farmers, too, knew that if you wished to improve a poor soil it was good policy to grow clover (belonging to the same tribe) on it, and to dig the whole crop into the earth after it was grown.

Scientists worked patiently to explain the riches of the leguminous (pea and bean) tribe, for it was quite clear that they possessed more nitrogen than they had any right to! At least according to their known and acknowledged sources of wealth. Really it was quite a pretty mystery! And who knew what deadly secret might be lurking beneath the surface! Nitrogen is the most precious of all the plant foods and what is more it is limited in supply, at least in a form that can be assimilated by plants, for there is plenty in the air. But it had always been held that the fixing and using of the nitrogen in the atmosphere was impossible with green plants, and all the experiments made confirmed this. It was a pity, because the precious nitrogen in the soil was constantly wasting, some of it escaping into the air in the course of the disintegration of decaying animal matter, and much disappearing into the sea owing to our wasteful systems of sewage. Certainly it was true that the soil seemed to have the power to convert the nitrogen of manure and decaying matter into the form of nitric acid, which could be used by plants, but this was evidently not the source of the secret supply of the leguminous plants, for, as I said, they were found to be rich when growing on pure sand!

In 1876 M. Berthelot again raised the question as to the possibility of the fixation of the nitrogen of the atmosphere by plants. In the following year two French chemists made the discovery that the power of the soil to convert raw nitrogen into the combination suitable for plant food was due to the action of two kinds of bacteria, one of which did the first part of the work and produced nitrous acid, and the other finished it and converted the nitrous into nitric acid. Perhaps this gave a hint as to the truth about the secret wealth of the Leguminosæ. Anyhow—I think it was a few years later—Professors Hellriegel and Wilfarth at last discovered, after many experiments and most patient investigation, the source of this wealth, which they proved to be due to an alliance between these plants and certain bacteria which formed little swellings or nodules on their roots and dwelt therein as very paying guests! These bacteria appear to have become specialized to the different species of the pea and bean tribe, and each one of the latter has his own special guest, though all are of the same race and have the same power of fixing the nitrogen of the atmosphere when growing thus on the roots of their host, and rendering it available for his use. It is believed that the host plant may supply the bacteria with some of their needs, possibly with carbo-hydrates, and also is useful in removing the waste products of the little colonies of bacteria and so keeping them in health.

One might tentatively suggest that it is possible that these guests of the Leguminosæ, whilst having the power to 'catch' and 'fix' the free nitrogen in the air, cannot assimilate it until the green chlorophyll granules in the host plant have prepared it as they do with all mineral matter taken up by the root. For, as far as is known, the chlorophyll in the cells of green plants is the sole agent in preparing inorganic substances for the use of plants—and therefore of course incidentally of animals.

It seems quite certain that there are advantages on both sides in this alliance or symbiosis, as it is scientifically called, and it appears to be a perfectly honest and legitimate means of obtaining the precious nitrogen. Moreover, incidentally, it increases the wealth of the world, for any means of fixing the nitrogen in the air and rendering it available for the use of living things is more precious than rubies, seeing that nitrogen is certainly more valuable than gold!

And what are these useful little bacteria which come to dwell in secret with this special tribe amongst the green plants? Are they animal or vegetable? The question was long disputed, for in these very low and primitive forms of life these are not easily distinguished the one from the other. But finally the verdict has been that they must be classed as vegetable, and included amongst the fungi. The reasons for the decision are based on their structure (the fact that they are enclosed in a capsule of cellulose which is not the case with the animal in its earliest manifestation), their manner of growth and development, and the fact that they are apparently able to feed on elementary substances although they have no chlorophyll.

They are like animals in having some power of motion, but this is quite common in the lower forms of vegetable life. They are like the ordinary fungi in having no chlorophyll and in depending to some extent on organic substances as food, but unlike them and like the higher plants in having the power to take in and use inorganic substances, such as the nitrogen in the air. But this, as I have suggested, may be due to co-operation with their host. Altogether they are a peculiar and puzzling tribe. But we may take it that this symbiosis of the leguminous plants with their special bacteria is an alliance between highly developed plants, which have been led by the Life-Force during thousands of years to a complex and special form of perfection and adaptation, and one of the simplest and lowest, or perhaps a degenerate form of Life's children in the same vegetable world, for mutual benefit.

It is believed that these organisms of the nodules pass the winter, when their hosts are usually dead or resting, as spores, or seeds, in the soil.

Maria Dawson, in a paper concerning research on this special matter, which was communicated by Professor H. Marshall Ward to the *Philosophical Transactions* of the Royal Society of London, gives very minute descriptions of the life of these organisms and their behaviour under culture in the laboratory, and she remarks: "it may now be assumed as proved beyond question that we are dealing with independent organisms which have become very specially adapted for life within the cells of leguminous plants—a specialization which varies with different hosts." So far, apparently, has this specialization gone in the case of the little 'guests' that when 'cultivated' on various ordinary media used in the laboratory growth was either non-existent or extremely slow, and in some cases the cultures died after a short time, but they grew rapidly on gelatine media *containing a decoction of pea stems or leaves.*

On the other side, the hosts seem to have become equally dependent on their little guests in many cases, as is shewn by the same research worker's interesting account of a plant belonging to the leguminous tribe called Desmodium gyrans, a native of Calcutta. She writes as follows: "The study of the nodules of this plant was suggested by experiments which were being conducted by Mr R. Lynch in the University Botanic Gardens, Cambridge. For some time he had found it impossible to cultivate this plant with any success in ordinary Cambridge soil, nor had nodules ever been observed upon the roots. In October 1898, in view of what was known regarding the organisms of the nodules of Leguminosæ, the attempt was made to grow Desmodium in its native soil from Calcutta, with the result that healthy plants bearing flowers, fruits, and seeds were secured, and in addition numerous nodules appeared on the roots." Miss Dawson does not feel convinced that the above result was due to the absence of the proper 'guest' of the Desmodium in the Cambridge soil, but thinks it possible that that soil had some injurious factor which rendered the plant unhealthy and prevented the organism from entering the roots: but however this may be, it was perfectly clear that Desmodium was miserable and only half alive without its familiar guests!

The different members of the leguminous tribe have each their special form of this organism, and Professor Nobbe has proved by experiment that—for example—if a supply of the organisms obtained from a pea-plant, and cultivated in the laboratory, were added to the stock of a pea-plant it became still richer, but if the organisms obtained from a lupin were given instead the result was not nearly so great.

This same Professor Nobbe has apparently found that the leguminous plants are not entirely alone in this symbiosis, and has described some others* which, by the aid of a different organism forming nodules on their roots, also obtain nitrogen from the atmosphere.

George Newman, demonstrator of Bacteriology in King's College, London, remarks that " there is very little fixation indeed " (of nitrogen) " by bacteria in the soil apart from symbiosis with higher plants." All this leads us to realize what an extraordinarily important work is being done by this great family of the leguminous plants in response to the leading of the Life-Force. Compare their prosperity and universality with that of the parasitic plants that took the opposite road. The pea and bean tribe is perhaps one of the largest and most prosperous in the world: only think for a moment of all that it comprises, even in our little British Isles; of the peas and beans of our gardens, the rich clover fields, lucerne, sainfoin, and trefoils, the immense army of vetches, the furze and brooms of our commons, the lupins and sweet peas of our flower garden, and the Robinia (generally wrongly called acacia) trees, laburnums, and countless other plants, shrubs, and trees in our cultivated places. What a contrast indeed with the partially successful eyebrights, bartsias and rattles, and the far rarer tooth-wort and orobanches (broom-rapes) which 'met the situation' by a different road. One can hardly doubt which is the true way of evolution, for of course the Life-Force is urging towards life, and " life more abundantly", and the wrong way is that which eventually leads to poverty and extinction.

In this little book I am trying to keep as far as possible to the life that exists around us in the British Isles, and I prefer, when I can, to speak of that of which I have some personal knowledge. We are not so spectacular in our little island flora as the great tropical and subtropical countries with their forests and jungles, and marvellous vegetable growths, but we have all the principles of life and growth before us, and enough and more than enough for the study of several lifetimes if we had them to spend. Anyone can study these little nodules of the nitrogen-fixing bacteria on leguminous plants with the greatest ease, as I have done in past years. Pull up the first little clover weed that you happen to find growing on your gravel path or on a rather poor-soiled and neglected flower bed, and I think you will find that its fibrous roots are pretty thickly studded with what look like minute knots or tiny granules. These are the clover's little guests, and you can, if you feel inclined, wash the little root from soil and plant the wee clover in a pot containing nothing but wet potsherds and damp moss and set him to shew how he can make his living in that poverty-stricken medium.

Calvary clover, sold by seeds-men as a curious and interesting plant from Palestine with 'blood-stained' leaves, has very large nodules on its roots; so have the yellow lupins as to which my brother consulted me, and of course this was the secret of their rich growth on the barren sand. Or you may study the root of a pea or bean. But do not expect to find the nodules on quite young seedlings, for they take some little time to establish themselves on the rootlets, as is natural.

As a testimony to the practical value of these bacteria I quote a short paragraph which appeared very recently in the *Times*—an epitome of a letter to the editor: " There would appear to be much truth ", says the writer, " in Mr Miln's statement that cattle prefer grass which has obtained its nitrogen from the air through the bacteria that are fostered by clover, for in a field in Hampshire, of which half was treated with these bacteria, the cattle always congregated in that half." It is not quite clear from the above in what form the product of the clover bacteria was applied, but there are now, I believe, chemical preparations of nitrogen obtained from these, and probably this is what is intended.

Before passing on to a further study of symbiosis in two plants of lowly organization, I should like to mention, in connection with bacteria of the soil, a simple experiment which I once made which seemed to throw light on a special usefulness of some species of these workers in our chalk soil. I had noticed that the rich leaf mould from the beech trees seemed to have a wonderful power of breaking up the hard chalk and rendering it fit for plant-food, and I wondered whether the effect was due to some chemical action of the decaying leafy matter, wetted by the rain, or if it could be the work of bacteria. So I tried a very simple little experiment, putting some lumps of pure hard chalk into two boxes and covering the one with freshly gathered leaf mould and the other with used tea leaves. I exposed both boxes to the weather and left them for a few weeks. When I examined them, I found that the chalk in the box covered with tea leaves was unchanged, whilst that with the leaf mould was disintegrated and fast changing both in consistency and colour. From this I make more than a guess that the tall beech trees have little unknown friends under their shadow who are busily at work amongst their decaying leaves (on which possibly they subsist) preparing the raw material of the chalk for the use of their higher brethren.

The story of the Leguminosæ and their paying guests is distinguished from that of parasites living upon a host by the circumstance that both the host and guest profit from the arrangement; it is in fact a co-partnership. I suppose in every such association the more dependent of the two must suffer some loss of self-sufficiency; and even the host may come to depend on his partner to a very definite extent, as we saw in the case of Desmodium gyrans when deprived of his friendly bacteria. Nevertheless we need not feel that the bann of parasitism attaches to these co-partnerships, and in certain cases they are extraordinarily successful.

A most interesting story, only lately more or less disentangled, and even now the subject of much controversy, is that of the lichens, now known to be a symbiosis of minute green algæ, (a lowly form of plant one-celled or with filaments composed of rows of cells) with special fungi, each alga entering into partnership with its chosen species of fungus to form a distinct lichen. Probably we all know certain lichens by sight and recognize them as such. The hoary growths so common on fir trees and often used by birds to build the walls of their nests, the beautiful grey-green leaflike growths closely applied to the stems of beech trees, the brilliant yellow patches on walls—these and many others are quite familiar to us as lichens, but the variety is immense and there are a large number which the ordinary person confuses with moss and others of the gelatinous kinds which he is apt to take for a simple fungus. The so-called Iceland moss and Reindeer moss are well known species of the vast tribe of lichens.

The history of the gradual discovery of the true nature of these organisms, their exact composition, character, and life-history, with minutest details of their being and becoming from every angle and point of view, has been given to us in several comprehensive works by Miss A. Lorrain Smith F.L.S. To her work I am mainly indebted for details of the history and life-story, as far as now known, of these interesting co-partners.

I have spoken of their union as a symbiosis, but it must at once be confessed that there is still much controversy as to whether they are truly so to be described or whether the association is really that of a fungus parasitic on an alga which is imbedded in its tissue. When a lichen is examined microscopically it is found to consist of a tissue of jointed filaments without colour enclosing small green bodies containing chlorophyll. Sometimes the latter are all gathered into a narrow band just beneath the surface within the tissue of the fungus; in other cases they are scattered throughout its substance. What is the nature of these small green bodies? This was the problem which faced early investigators. It was decided that they were brood-cells, or reproductive organs, and they were named Gonidia, a word that is still used to describe them though it is now known that they are living algæ belonging to species well known in a free condition. It was noticed that when a sort of vegetative reproduction took place in the lichen and small portions of its substance detached themselves and grew into new individuals, there were always one or more of the green bodies included, and this supported the idea that they were reproductive organs. It was not long before it was discovered that Gonidia could be found growing free on the barks of trees near the lichens, and it was suggested that these were "unfortunate brood-cells" which had broken away from the body of the lichen and could no more reproduce the perfect plant, though strange to say they could and did grow and increase by division. This fact was certainly puzzling but it did not, apparently, shake the faith of the early investigators in the truth of their theory as to the nature of the Gonidia. Even when they came to recognise the green cells as known algæ they seem to have decided that the plants hitherto recognized as perfect algæ must be merely. imperfect forms of lichen, and the theory was advanced that these Gonidia were the female organs of the lichen and could only produce their kind after fertilization by spermatia which they discovered in certain fructifications of the lichen and considered to be the male organs.

After a time, as the investigations proceeded, cultures of the Gonidia were made, and not only did the green cells increase by division, but zoöspores, or motile spores (reproductive bodies) common in the lower plants, were produced by them and gave rise to new groups of cells. Still the observers called them "vegetating lichen Gonidia", and failed to understand what they saw. They next tried to discover the origin of the green cells in the body of the lichen, and some thought they saw them develop from the colourless filaments (of the fungus). But now at last the suggestion was made that they were organs of nutrition and not of reproduction.

Finally in 1860 Schwendener advanced the theory that the Gonidia were really algæ after all, and that lichens were cases of algæ caught and preyed upon by parasitic fungi. After that cultural experiments followed fast.

I must explain that the lichens were seen to reproduce themselves not only by the vegetative process mentioned above but also by another method common amongst the lower plants, namely by spores produced in special receptacles. These arose always (as did the receptacles bearing spermatia) from the filaments of the fungi, and the algæ produced no organs of reproduction. The investigators now sowed the spores from the fungi both on a medium containing the proper alga belonging to the lichen they were observing, and on a cultural medium without the alga. In the former case true lichen plants were developed, in the latter only the colourless filaments of the fungus appeared, and these soon died off unless a specially suitable food was provided in the medium in which they were grown. Free Gonidia had already been cultivated, as we have seen, but now Gonidia isolated from the tissue of the lichen were grown, and the result was the same. The alga could live and increase without the aid of the fungus, propagating itself both by division of cells and by the production of asexual zoöspores. (We shall hear more of these in a later chapter.) In one or two cases the threads from germinating spores of a fungus, being introduced to their proper partner, were seen to attach themselves to this gonidium. It became clear that whilst the algæ can and do carry on an independent existence when separated from the fungus, the latter has so far suffered a loss of independence that it can only exist without its partner in special circumstances where its support is secured, and it is unable in such conditions to form spores and to reproduce itself. Yet it occupies the more important part apparently in the co-partnership, its tissues in most cases building up the main body of the lichen and the organs of reproduction belonging to it and not to the alga. Without going into a full description of these organs, about which there is still much controversy, I will just remark that besides the spores before-mentioned, contained in open or closed receptacles, there are other receptacles containing spermatia which by some observers are thought to be the male organs of the lichen and to find a mate in an imbedded thread-like coiled filament, which after two or more coils proceeds straight to the surface of the tissue, its last cell projecting and forming the signal to the spermatia. According to these observers, the fertilization of the thread-like coiled filament results in the formation of the ordinary receptacles containing spores. However, doubt has been cast upon this view, and in some cases spermatia where sown like other spores have germinated like them. It will be seen that there is still much mystery about these curious joint beings.

In 1873 Reinke expressed doubt as to the true parasitism of the fungi involved, on the ground that both partners lived in perfect health and had greater longevity than when living separately and that the algæ did not appear to suffer in any way.

Various words were suggested to express the joint life. *Symbiosis* and *Commensalism* are those most generally used at the present time by botanists who reject the former view of the case as one of parasitism.

Observers now concentrated on the crucial question: did the fungi prey on their algæ, or did the two live in loving co-partnership? Were the algæ slaves imprisoned in the folds of trees or other substratum on which it grows, and even from the decayed bodies of perished Gonidia within its folds!

We naturally ask how the Life-Force regards this association and how far it has been blessed in the ages of evolution. And the answer is that the lichens are perhaps the most widespread and enduring of all vegetative growth. From the sea shore to the tops of barren mountains they climb: in the tropics and in polar regions specially adapted forms flourish; some can exist wholly or partially under water and others on sand-dunes and even in the desert. Accounts of the numbers of known species vary, but in 1898 Fünfstück estimated about 4,000 well-authenticated species, and many additional genera and species have been discovered since then. The reindeer rely on certain kinds as their main food, and some lichens have been useful to man in various subsidiary ways, to some small extent as food, also as medicine, and in the manufacture of dyes. But the main work entrusted to lichens by the Life-Force is a far greater and a deeply important one. They are the pioneers of vegetation, the first soil-formers in desolate regions and on bare rocks which can support no other vegetation. Miss Lorrain Smith writes: "The part played by lichens in the economy of Nature is of very real importance: to them is allotted the pioneer work of breaking down the hard rock surfaces and preparing a soil on which more highly developed plants can grow." And she reminds us of the description of this work by Linnæus whose words I venture to re-quote as they are so exceedingly interesting in this connection:

" Crustaceous lichens " he writes, " are the first foundation of vegetation. Though hitherto we have considered theirs a trifling place among plants, nevertheless they are of great importance at that first stage in the economy of nature. When the rocks emerge from the seas, they are so polished by the force of the waves that scarcely any kind of plant could settle on them, seen more especially near the sea. But very soon, in truth, the smallest crustaceous lichens begin to cover those arid rocks, and are sustained by minute quantities of soil, and by imperceptible particles brought to them by rain and by the atmosphere. These lichens in time become converted by decay into a thin layer of humus, so that at length imbricate lichens are able to thrust their rhizoids into it. As these in turn change to humus by natural decay various mosses . . . follow, and find suitable place and nourishment. In time there is produced by the dying down of the mosses such a quantity of soil that herbs and shrubs are able to establish themselves and maintain their existence."

It appears that the acids contained in lichens have a powerful effect in disintegrating rock; oxalic acid—very commonly secreted amongst others—seems to be able to reduce minerals and even powdered glass! The excretion of carbon dioxide by these plants acidifies the moisture which they hold, and this likewise acts upon the substratum, whatever it may be. Granite is said to be reduced to a " claylike, yellow, granular mass" in a short space of time, and under these vegetable disintegrators with their solvents the rocks become soft and friable and in some cases "can be sliced away with a knife."

One asks: could this pioneering work—so absolutely necessary in the interests of life upon this earth—have been equally well performed by either of the two symbionts in the lichen plant, growing separately? Several reasons incline one to think not.

It is true that algæ are found as the pioneers in certain difficult situations, and they must certainly have had an important part to play before lichens were 'invented'! Fungi in their pure state could not very well do this work, being by nature saprophytes, depending for food upon decaying vegetable matter. But lichens are more resistant of extremes of cold and heat than any other plants, and can grow in polar regions and on heights where all other vegetation must perish. They also have the power of persisting for a long time in a state of suspended vitality. Thus in the climatic variations and catastrophes which this globe has witnessed through past ages, the lichens might persist and hold the world for vegetation where nearly all other plant life was for the time obliterated. Further, one must realize that both of the associated plants in the lichen are much changed and modified by the symbiosis. The body of the plant is, in the more shrubby kinds of lichen, mainly the contribution of the fungus, which has been stimulated to build up a framework suited to the requirements of the joint life; in some others, such as the gelatinous kinds, the alga takes a prominent part in building; but in all cases special provisions have to be made. Space must be made for the work of the algæ to go on—where possible in some degree of light and air—also for the storage of nutritive material, necessary for plants no longer living from hand to mouth and with a long joint existence in view wherein periods of dearth must be expected; and protection must be afforded for both partners from conditions of climate. Thus we see that not only is their structure better adapted to weather out extremes of climate than that of simple algæ, but also that in their natural decay they leave far more substance for the next-comer to feed upon. Covered with a superficial crust, the lichens of types that disintegrate the smooth rock work with their root-like filaments, pushing their thin fingers between the minute crevices, whilst the algæ, close to the surface and obtaining light and air through the tissues that enclose them, ardently pursue their avocation in the production of carbo-hydrates as sources of energy.

It is certainly a union for mutual advantage and is beneficial in the economy of Nature, and the Life-Force has blessed it exceedingly. One finds the two principles of sacrifice and co-operation displayed in these lowly plants; sacrifice in that, as I mentioned earlier, a certain loss of independence is almost invariably the result of close co-partnership, and the fungus, at all events, is less capable of individual persistence without its partner. But there is gain, both individual and racial; the life of each partner is greatly prolonged by the association, and "life more abundantly" has been granted to them.

CHAPTER V

FURTHER ADAPTATIONS. ANOTHER METHOD OF MEETING A DIFFICULT SITUATION

In the two preceding chapters we have followed the fortunes of two groups of plants which, urged by the Life-Force to find sustenance in the face of poor circumstances, have met the situation in two different ways. The one group frankly steal what they require from others—also children of the Life-Force—which can hardly be expected to be an approved method. The other group take in paying guests or unite in close symbiotic association and prosper exceedingly. It must be remarked that it is very frequently from these same rich and prosperous hosts that the parasitic thieves steal their supplies. You will remember that the dodder chooses the clover and the gorse as special hosts, and the rattle is also partial to clover, whilst certain of the broom-rapes choose the shrubby leguminous plants, and others the clover for their hosts. This certainly seems hard on this honest tribe, but notwithstanding such losses they are well able to hold their own in the general struggle and they stand high in the ranks of the plant world.

There are two commands which seem laid upon all life by that which brought it into being, and to fail in obedience to either means extinction. The first is to find sustenance wherewith to build its own body, and the second is successfully to reproduce its kind. There is no instance of complete failure in either of these, simply because to disobey the first means personal extinction and to fail in the second the extinction of the race.

The group whose response to difficulty I want to describe next have found trouble in the same question of supplies which met the two groups discussed in the last chapter. Like the lousewort, they are bog plants, and nitrogen appears to be scarce in such conditions. The little sundews have found a new and strange way of supplying this necessity, which, though not, I am convinced, in the true line of evolution to which the Life-Force seeks to shepherd its children, is yet extremely interesting as shewing the possibilities of functions that we have thought of as purely animal in the vegetable organism.

Stepping warily over the bogs of Dartmoor, with their deceptive green patches and the safety land marks which one learns by experience to know, one is sure presently to be struck by the beauty of little ruddy plants glistening with myriads of ‘ dew-drops ’ held by the rosy hairs which give their leaves their apparent colour. If it is the month of July when one first sees them they have little flowers borne on long stalks like a saxifrage, and if one is *very* lucky and it is a happy, sunny morning, one may have the none too common experience of finding some of these white starry blossoms amongst the ‘ dewdrops ’ with their eyes open to the sun. Some of the plants have round leaves and some long ones; the former are the round-leaved sundew (Drosera rotundifolia) and the latter are the long-leaved (Drosera longifolia) or possibly the Great Sundew (Drosera Anglica) which is like the long-leaved, but larger, and a rarer plant. It is found in Devonshire, however. These three bog plants all require a boggy soil, without lime or chalk; and where the sphagnum moss grows, in the

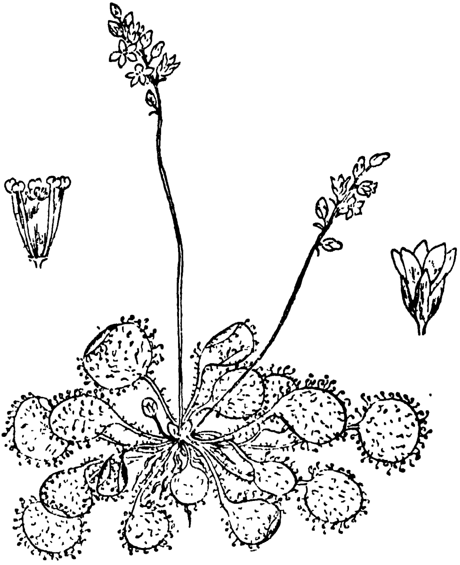

Fig. 17—The Sundew.

North of England, and in Scotland, the sundew may often be found with its roots merely buried in that deep soft cushion and not touching soil in any way. One can understand that plant food of a nitrogenous character is very scarce and in some cases hardly to be obtained by the roots, yet it is a necessity of plant life.

Looking closely at the small ruddy plant one is almost sure to notice that one or two leaves are rolled up and seem to hold something as in a closed fist. If we unrolled them by gentle force we should discover the remains of some unwary fly or other insect, which had been attracted by the shining ‘ dewdrops ’ and alighted on the surface of the leaf. Alas, things are not always as they appear, and the shining drops proved to be no refreshing drink but a viscid sticky juice in which he soon was caught and held. Meanwhile, those beautiful little rosy hairs were surely moving, bending over the victim and binding him down! Yes, it was useless to struggle, the leaf itself was slowly but unrelentingly rolling over him, engulfing him in an acrid liquid, which—terrible to relate from the insect's point of view—was actually the digestive juice which was to render him fit for absorption by the leaf of the hungry Drosera, as a beefsteak is prepared by the pepsine of our digestive apparatus.

In short, we have to do here with carnivorous plants feeding on animal life which they have become marvellously adapted to catching, holding, and digesting, their movements during which processes, and the manner of their digestion of its substance, seeming to bring them into extraordinarily close relations with the animal life on which they have learnt to prey! Indeed, Professor E. Morren, a Belgian botanist who has devoted himself to especial study of the carnivorous plants and of their movements and digestion, remarks that this power of digestion is their essential character and, alone, would be almost sufficient to raise them to the dignity of animal life.

Many experiments have been made by botanists and scientists upon these curious little plants, both as regards the wonderful movements of the rosy tentacles and of the leaf itself, and as regards their power of digestion of their prey. Many years ago, when staying at Chagford in Devonshire, with my children, I made a series of experiments myself with sundews which I took home from a neighbouring bog and planted in various pieces of crockery for purposes of observation. In spite of some casualties through the occasional throwing down by the children of a soap-dish or utensil containing a plant under experiment—almost inevitable in our small sitting room—I managed to carry through a number of very interesting observations, of which I have the careful notes made at the time. Various facts came out very plainly. I am really afraid I subjected some poor little plants to very drastic tests in my desire to find out how closely they approached to the animal stomach in the apparatus of their leaves; and I am almost sorry for three leaves which were first dosed with alcohol in the respective forms of red wine, whisky, and methylated spirit, and then only a few hours afterwards, when, according to my notes they " looked very unhealthy and the glands appeared dried up as if they could not secrete ", they were all three fed with cream! Very naturally, they could make no use of this, though a healthy unalcoholized leaf fed at the same time held its drop of cream " in a round globe shape by the viscidity of its secretions from the hairs which bend round the drop." The cream on the alcoholized leaves spread about or soaked into the leaf, and was obviously no more digested than if on a leaf of an ordinary plant. Another meal of milk was given later on with the same result, and then—as a final effort to restore their digestive power—I find that I " put a drop of pulsatilla into a teaspoonful of water and gave each leaf some, to try if it would restore the power of secreting mucus." No use! " The pulsatilla has had no apparent effect, and the alcohol has, to all appearance, destroyed the three leaves as far as their power of secreting viscid fluid is concerned." These leaves never recovered and became shrivelled and died. I attempted the experiment of giving whisky and water to plants in the bog; the results were rather inconclusive and difficult to check, but as far as I could judge the whisky had a harmful effect, though doubtless counteracted by the amount of water in the air and surrounding soil.

So much for the effect of alcohol. Now as to the effect of milk and cream. This was evidently not a suitable food, owing to the fat that it contained, and though it excited the digestive apparatus and caused all the tentacles to bend over the drop, as described above, the result was far from satisfactory. In a healthy leaf fed with cream I noted that in two-and-a-half minutes it began to be affected, the hairs bending over; eventually it rolled over the drop as it would do with a fly. Later on the notes record: "Leaf fed on the 15th (a week before) with cream has opened out, but is throwing out upon its hairs all round a white curdy substance. Apparently it had found the curds into which its digestive juice has transformed the milk very indigestible and had resolved to eject them." Later on I find: "Leaves fed on 20th with Devonshire cream have opened again and evidently consider the cream, which remains unabsorbed, an unfit subject for consumption." The same result occurred in later experiments and the conclusion I drew was that the *fat* in the cream was indigestible to the plant as one would expect, seeing that in our own bodies it is not the pepsine which disposes of fat. Butter and mutton fat were accepted by the leaf for the moment, but not utilized. My notes record an unhealthy appearance in the butter-fed leaf, and an anxious reference to the possibility of salt in the butter! Later on there is a record: "leaf fed on the 23rd with mutton fat has completely opened, leaving the fat untouched." And a note is made further on: "Fat cannot be assimilated."

Now as regards the purely nitrogenous foods, the experiments were very interesting. Leaves fed with cooked veal, mutton, chicken, and fish digested their meal most successfully and opened healthily again. In the case of the one fed with veal (which proved to have an exceptionally strong digestion), there were " no trace or remains of its meal upon it," but this is not usually the case, as in later records I find: " leaves fed with mutton on 18th nearly open again " (this was on the 24th). " In each case there is a slight deposit of greyish and black matter which will probably be thrown out on the hairs."

White of egg was well digested but left a " blackish deposit on the leaves ", and the record speaks of their having a rather unhealthy appearance. Yolk of egg and raw meat had a curious result. They were accepted with great avidity by the leaves, which quickly seized on them with their tentacles and poured their juices upon them, rolling them up eventually in close-fisted greed. After a time, however, the record speaks of the unhealthy appearance of the leaves as they begin to open. There is a black deposit and the " hairs are crumpled and no drops on them." Again: " Another had partially opened with the same crumpled appearance and a large black deposit "; and again: " Leaves fed with raw meat all appear unhealthy and as if their meal had not agreed with them. None are fully open yet. There is usually thick black deposit and the leaves are dropless and crumpled." Finally, a few days later: " Examining the leaves fed with raw meat on the 18th (nine days previously) which look very unhealthy, I see that the cause of their trouble seems to be the very thick and hard black deposit which, after a large meal, is left in such quantities as to stick their hairs down and prevent the leaves from opening again. I think I have probably given them too much for their digestive powers and they are dying of surfeit." Occasionally a leaf will prove equal to its task: "the leaf fed with cooked veal and subsequently with raw meat evidently possesses a strong digestion and its juices have lasted out the meat and kept it in a soft condition ready for assimilation. Its hairs will therefore be held down by no hard black deposit and it will probably do well." But the final conclusion is: "Raw meat given in large pieces is evidently too great a tax on the digestive powers of the Drosera. Cooked meat, veal, chicken, etc. make less glutinous deposit and seem more easily disposed of." This is really very natural when one thinks of the exceedingly small amount of 'meat' on the body of a midge or small fly which would be a normal meal.

Finally an experiment was made as to the effect of chloroform on the plant. At first I touched the leaf itself with pure chloroform, which very naturally burnt it and destroyed the glands. Seeing my mistake, I "chloroformed a whole plant by placing it under a tumbler with cotton wool soaked in chloroform." An hour later: "Fed two leaves of the chloroformed plant with raw meat, replacing the tumbler and chloroform immediately." Three hours later: "Took the chloroformed plant from under the tumbler and found it to be healthily digesting the raw meat, quite unaffected by the chloroform." Next day: "chloroformed plant seems digesting as healthily as the other plants fed with raw meat." I think it is obvious that in this very rough experiment the unknown amount of chloroform was not sufficient to anæsthetize the plant. In this case it might possibly even act as a stimulant. Sir J. C. Bose in his experiments on plants subjected to anæsthetics describes the effect of chloroform as strongly narcotic. He, however, remarks that diluted chloroform vapour was observed at first to have an excitatory effect.

The experiments on the digestive power of the leaves agree, I think, very well in their conclusions with those of scientists. Anyone who has in his childhood fed sea anemones, kept in a tin bucket or basin, with bits of meat and other unaccustomed foods will know very well how easy it is to upset the poor animal seriously and to give it an indigestion which may even endanger its life, but one is hardly prepared for the same results in a plant. Yet Professor Morren gives an amusing though tragic account of the experience of a Mr Canby (an American botanist) who lost a specimen of Venus's Fly-trap—a most interesting carnivorous plant of N. Carolina—by forcing it to eat cheese! Doctor Balfour (also a compatriot of Professor Morren I believe) wished to verify this sad experiment and gave a meal of Cheshire cheese to one of his plants on July 8th, 1874. On the 9th he thought it seemed upset and inclined to eject the meal. However, all seemed to go well for some time, the Venus's Flytrap having normally a very slow digestion. But on the 21st what appeared to be bilious trouble supervened, the leaf became yellow, then black, and died of true indigestion!

Professor Morren speaks of oil and fat as indigestible by carnivorous plants. He also describes an experiment in which as much meat was given to several leaves as they could be induced to take. The next day they were evidently suffering from a surfeit; some of the leaves were relieved by forcible removal of their large meal and these were saved, but the remainder shewed evident signs of severe indisposition.

Professor Morren made an unhappy experiment with a pet Drosera which he was growing for pleasure. It occurred to him one day to give it half a pill of pepsine—I suppose to help its digestion—which he afterwards remembered contained a minute quantity of nux vomica. In two or three days the poor little plant was very ill: all the glands of its leaves dried up and all the leaves faded and died one by one.

From this experience it seems quite clear that the *plant* absorbs what the leaves digest, and this fact was practically proved by M. Clarck who gave his Drosera flies treated with citrate of lithium, and a few days later, analysing the plants with the spectrum, shewed this metal in every organ, even in those of the inflorescence!

We shall naturally ask how the sundews came to adopt this strange habit, for we know that in plant life such developments must come little by little, and generally, in the first instance, by some fortuitous circumstance or change which proved valuable.

In the case of carnivorous plants the stages on the way to that habit of life seem pretty clearly marked in plants which still exist. A large number of 'fly-traps' are to be found amongst plants belonging to different families, and although these do not digest their catches in all cases, yet it is believed that the bodies of such insects during their decomposition yield some carbonate of ammonia which is absorbed by the plant. Examples of such cases are the Saxifrage tridactylites, provided with glandular hairs by which small insects are held englued; various 'catchflies', or forms of wild silene with sticky stems often crowded with dead insects in summer; the henbane and, according to Anne Pratt, the purple loose-strife of the river bank. In the Christmas rose, whose beautiful white flower-leaves are really sepals doing duty as petals, the true petals are reduced to small green tubular pouches containing honey, which are believed to attract and kill the insects often found in them. How far they digest them I do not know, but it seems like the beginning of such a habit.

The bladder-wort (Utricularia vulgaris) of our ditches and ponds is an interesting case. It has bright yellow flowers and finely divided, often thread-like, leaves. Little bladders or pitchers, green, purple, or pink in colour, are attached to the leaves and shoots. At first these are filled with water, but at flowering time they rise, the water escapes, and they become filled with air which holds the plant up to expand its flowers in the air and sunshine. After the flowering season they again fill with water and sink the stems, so that they may sow their seed at the bottom of the pond or ditch, in the mud. Each bladder has an opening with a sort of lid, and the little inhabitants of the water, entering, cannot get out, and perish there, when it is believed that their decaying bodies may, as in other cases, afford a supply of nitrogen to the plant.

The butter-wort (Pinguicula) seems very near to the sundew in its methods, and is often to be found growing close to it in the bog. Its pale yellowish rosette of leaves with a long-stemmed flower, something like a violet to the casual glance, rising from its centre, is very attractive. But when you touch the leaves you find they have a clammy, greasy feeling, and presently you discover that they have a tendency to roll up *at the edges*, not from tip to base as do the sundews, upon the irritation of an insect settling upon their sticky surface and struggling to be free, and to close over the insect and kill it. That there is some power of digestion seems probable as the leaves will coagulate milk when laid in it, and it is said to be used by the Swedes and Norwegians for this purpose, also by the Laplanders for preparing a kind of sour milk which they appreciate.

The sundew is the furthest advanced of our native carnivorous plants, but in other countries there are still more wonderful adaptations for the catching and devouring of animal prey. I have already mentioned the well-known Venus's Flytrap (Dionæa muscipula). Dr J. E. Taylor gives an admirable description of this plant, from which I quote:[1] "The footstalks of the leaves", he writes, "are flattened out . . . . and perform the functions of true leaves, so that they leave the latter free to be adapted to other duties. This remarkable plant has its natural home in the damp and swampy places of North Carolina. The edges of the true leaves are set all round with stiff bristles, which interlock like the fingers of the clasped hands when shut, and if anything happens to be included within them it is held prisoner there. If it should be a particle of meat or a fly it is retained, and subsequently digested by a fluid which oozes forth, and the organic matter is thus assimilated. When the blades of the leaf are opened, three stiffish hairs may be seen on each half, standing upright like sentinels. These are highly sensitive. A touch with a hair is sufficient to enable them to commence a series of internal protoplasmic changes of such rapidity that the blades close immediately like a mouse-trap. If an insect alights upon the leaf, and touches these sensitive hairs, it is then captured, strangled, and digested. But it may walk about with safety so long as no part of its body comes into contact with the telegraph instruments, as the hairs might be called."

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[1] *Sagacity and Morality of Plants*, J. E. Taylor, Ph. D., F.L.S., F.G.S.

Further on he remarks that Dr Burden Sanderson has shewn that the "contraction and contractibility in the tissues of the leaves of Venus's Flytrap are identical in their character with those which take place when muscular contraction occurs in the muscles of mammalia." Moreover, he has further shewn that "there is a correspondence between the electric phenomena which accompany muscular contraction and those which are associated with the closing of the leaves of the Venus's Flytrap."

We may have to refer later on, when considering the 'irritable' parts of plants and their movements, to experiments made by Sir J. C. Bose and his theories on the subject. Meanwhile the above interesting accounts seem to shew that here plant life has come exceedingly close to the functions of the animal. As a last case in this hasty survey of 'carnivorous plants', from those at the first beginnings of the habit, to the most highly specialized, I must mention the various Pitcher-plants—of which our little bladder-wort, who has some wonderful foreign cousins, might perhaps be looked upon as a sort of forerunner. These Pitcher-plants, the Nepenthes, Sarracenias, and Cephalotus, belong to different families and have different homes—some in North America, some in California, in Borneo, Madagascar, and some in Australia—but the principle of construction in all is much the same, consisting of a 'pitcher' (generally with a lid or hood, which is a modification of a leaf to a special purpose), containing a liquid partly composed of water and partly of an acid fluid secreted by glands in the interior of the pitcher. Sir Joseph Hooker, speaking of the Nepenthes, observes that "it appears probable that a substance acting as pepsine, is given off from the inner wall of the pitcher, but chiefly after placing animal matter in the acid secretion." A honeyed juice attracts insects to the mouth of this pitcher, and having once entered, it is difficult or impossible for them to return, owing to the hairs or stiffer bristles which all bend downwards, rendering the inward path easy, but that of return practically impossible. Some of these Pitchers reach an enormous size, one (Nepenthes rajah) will hold, it is said, two quarts of water. These frequently catch a larger prey, and mice and even small birds which have come to drink and crept into the pitcher have been found engulfed in it.

If we take it as an established fact that the nitrogenous matter obtained by all these plants from the bodies of their victims is of real value to them as a source of food, expecially when growing in a poor soil—and this is Darwin's expressed view—it is not difficult to see how the habit may have arisen. Flies or insects caught by some sticky secretion of the plant, killed by poisonous properties of the flower, or drowned by the water collected in some such natural basins as those formed by the united bases of the leaves of the common teasel, may prove useful to the plants in question as affording, by their decay, nitrogenous substances suitable for absorption by the leaves, and thus the first steps in the carnivorous practise may be begun.

That such substances can be absorbed by the leaves from the atmosphere, at all events in certain conditions, has been proved by experiment in greenhouses, where it has been shewn that a slight increase of carbonate of ammonia in the air has a markedly beneficial effect upon plants of the orchid family *without roots*, which depend for their supplies upon absorption by their leaves.

Professor E. Morren is very cautious in his summing up with regard to the utility of the carnivorous habit. He says that the sundews have been successfully cultivated in greenhouses when kept from the access of any insects and supplied neither with raw meat nor white of egg. But he does not say that these plants were cultivated in pure sphagnum moss or in the poor soil of a water-logged bog! On the contrary he speaks of clever gardeners who have known how to cultivate the "extremely difficult" carnivorous plants, carefully avoiding all trace of lime or chalk in the soil. He finally admits rather grudgingly that the power of insecticide in these plants does provide them with an excess supply of nitrogenous matter, and he rather wonders that they have not made a better use of it and grown into more substantial proportions.

Comparing the carnivorous plants in general with the great tribe of the leguminous plants, I think we shall feel that on the whole their strange development and manner of meeting the situation has not been blessed and rewarded by the Life-Force as has that of those who took in paying guests! As regards the great Nepenthes and other pitcher-plants of the tropics, I do not know enough of their real habits or conditions to presume to judge, but if we compare our native sundews, butter-worts, and bladder-worts with our army of vetches and clover, there is little question as to which has the more abundant life, or which is in the true path of evolution.

The leguminous family is one which, directly or indirectly, has been of the greatest service to man, but this fact must, I think, be taken as incidental in his history, for it is quite evident that the supply of man's necessities is not the main point in the urging of the Life-Force. It is surely something greater and grander than that, though it be partly hidden from our eyes as we look wistfully at the wonder of the higher branches of that great trunk of creation which seems to have separated from the animal at the earlier stages of life upon the planet. In those far off days it seems as if the groping beings within wee specks of protoplasm were—as ever—presented with a choice of roads. Some remained unenclosed, open to every avenue, ready to develop in response to every call of the environment, and these were the first animal cells; others on the contrary built themselves walls of cellulose for protection and defence and shut themselves, to some extent, away from intrusion and attack; these were the first vegetables. Edward Clodd, in his *Story of Creation* remarks: "the vegetable cells sealed their fate when enclosed within a thick, hard shell, because they became thereby less accessible to external influences, less able to combine for the construction of nervous and muscular tissues, than animals, and condemned to an automatic life." Yet the Life-Force must have wanted them for their special work, and it does not follow that their choice was a wrong one, only it differentiated them from the beginning from the animal; and however highly developed a plant may be, however far it be led upward by the Life-Force, it cannot, we believe, enter the animal kingdom; its province is marked out as a vegetable, and it belongs to that branch of life for ever. Of its special gift and life-work we may speak in a future chapter.

CHAPTER VI

REPRODUCTION

In the last chapters we have considered special ways in which certain plants have met the first command of the Life-Force, which is *to find sustenance wherewith to build its own body.* Disobedience to this, of course, would mean personal extinction.

Let us turn now to the second command which involves the life of the race for which the individual exists: *successfully and faithfully to reproduce its kind.* Here, what I spoke of in a former chapter as the exuberance of idea and resource resulting from the working of the Life-Force is surpassingly striking and remarkable. One is reminded of a theme in music taken up and varied in a hundred ways, lost apparently amid a rush of subsidiary developments, only to break forth clear and sweet in a new and more beautiful form, yet clearly recognizable as the perfect fulfilment of the simple theme which was sung at the beginning in so few notes.

The first principle of reproduction is well and simply put by Sachs in his *Lectures on the Physiology of Plants:* " All reproductive processes " he says " serve the purpose of producing new, independent, living organisms, and this is always accomplished by a portion of the substance of an already existing organism affording the material from which the new structure is to proceed."

There is therefore no new life without the giving of something from the living body of the parent. Now in certain vegetative processes of reproduction in the plant world, and indeed in that of the lower animals, there is a simple breaking off of a portion of specialized and ready developed growth to form a new individual. The runners of the strawberry, the violet, or the creeping buttercup are good examples of this: the underground stems or stolons of couch-grass, valerian, lily of the valley, perennial sunflower, mint, and a host of herbaceous plants so-called, are the same in principle, and the underground stolons must not be mistaken for roots, being truly branches, though without chlorophyll, possessing scale-like leaves and a leaf-bud at the end which develops into a shoot. In some cases they swell up into thickened stems called rhizomes and send down numerous roots. Many irises have this habit, also the common asparagus. In other

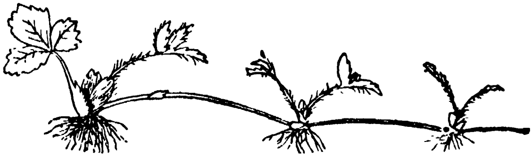


FIG. 18—The Strawberry Runner.

cases a thick tuber is formed at the end of the underground stem, and upon this buds are developed in the axils of minute scale-like leaves. The potato and Jerusalem artichoke are examples of this method, the 'eyes' of the potato being of course the buds of future shoots.

Bulbs are occasionally produced at the end of underground stems, but more usually the new bulb arises in the axils of the scale-leaf of the original parent bulb which is itself a development of the leaves surrounding the main leaf bud of the shoot, these becoming succulent and fleshy and full of nourishment for the plant, just as the tubers of the potato are provided with stores for the nourishment of the 'eyes' which are to grow into new plants. We need not dwell further upon cases of simple vegetative reproduction, though the variety of method even here is almost endless. We may note by the way that the characters of the parent are usually transmitted much more strictly by this kind of vegetative reproduction than when two cells combine to form a new plant by seed. This latter process, which we have mainly to consider here, opens the door to new possibilities of development, new elements, perhaps, and new chances, all of which are the opportunities of the Life-Force as it gradually urges the individual upward.

Yet there is a safeguard against unlicensed development from type, and it is a strange and interesting one. It is as if the organism must be deeply anchored in its past, though free to bend and respond to the winds and waves of circumstance.

This is spoken of as the Continuity of the Germ-plasm, and the way in which it is carried out is as follows: After fertilization of the female or egg-cell, the development of the embryo begins, and a wonderful differentiation takes place of the germinal matter into the various organs of plant or animal. Meanwhile a *certain reserve of undifferentiated material* is kept apart and is not used in building up the body of the new being, but is held in trust so to speak for the next generation. This residue goes to form the germ cell in the reproductive processes of the individual from which will be developed the next in generation. Thus it seems as if from the beginning a thread of inheritance is carried in trust, unaffected by the individual variations, to anchor it firmly to the past. Yet there is opportunity for mutation as the germ-plasm becomes enriched with heritable qualities brought gradually into being by response to environment and to stimulation.

The embryonic substance thus passed from generation to generation through "the slow course of geological epochs" as Sachs puts it, consists of such extremely minute specks of matter that we seem to be gazing down into the gulf of the infinitely little of which I spoke in the first chapter. Once again one is made to realize that 'great' and 'small' are but words adapted to our present state of being, and hav little real significance. Yet one must not think of the process of handing on the life as one of continual halving as in the figure that I used there, for the general body of the plant, its leaves and other assimilative organs, though themselves incapable of renewing their life, yet contribute from their store of nutriment that which is needed for nourishment of the embryonic cells in which the hope of the race lies. Hand in hand the two forces seem to work—the age-long trust committed to life when it first appeared, and the task of feeding and maintaining that germ and doubtless of enriching it in many new ways, by all the means wherewith the organism draws on its environment.

Before going on to speak more in detail of the two specialized forms of reproductive cell, we must touch on the subject of asexual generation in the lower plants. Though I shall have to refer to this again in the next chapter when discussing the likeness between animal and vegetable in their beginnings, yet I must make a few passing observations and give one or two examples here to make the story of the reproductive process clearer. And let us remark that *wherever* there is a new growing point from which a new individual is to proceed, there is a portion of the inherited germ-plasm passed on. In single cells which have the power to reproduce without the co-operation of another we must conclude that the whole of the inheritable trust is contained without division into male and female, and thus that all that is necessary for development is contained in the single cell. Higher up in the scale this seems not to be the case and the division into male and female cells renders each incapable of development without the other. That there is a deep meaning and reason for this separating and coming together of the elements of the germ-plasm none can doubt who observes the strenuous preparation and the effort and 'ingenuity' expended by the plant world in this one special direction. The fulfilment of the second great command of the Life-Force in this special manner seems to fill the whole horizon in the development of most of the flowering plants.

Returning to those earlier manifestations where there is neither male nor female but one cell is capable of reproducing the body of the plant, we may take the common yeast plant (Saccharomyces cerevisiæ) cultivated for use in brewing, as a typical example. Here the rounded cells are composed of a granular protoplasm and enclosed in an envelope of cellulose. Their ordinary method of reproduction is by a swelling which usually appears at one end of the cell, pushing out like a small bud. After a time there is a constriction of the wall between the 'bud' and the mother-cell; the bud increases in size and finally develops into a new individual. The various yeasts are to be taken as belonging

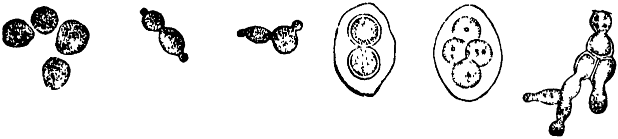


FIG. 19—The yeast plant, and its method of growing and multiplying magnified.

to the fungi though closely related to the algæ, and like the fungi in general they have no chlorophyll. Saccharomyces ellipsoideus is a sort of wild yeast which grows naturally on the surface of fruits, such as grapes, and causes their juices to ferment when the fruit is crushed. Thus it is the natural ferment of wine. Besides the vegetative reproduction by budding, the yeasts in certain circumstances and in the presence of free access to air, produce spores within their cells. In brewer's yeast the process is as follows: the cell swells up and the protoplasm becomes less granular in substance. After some thirty hours or so—more or less—four separate spores are formed within this parent-cell. These expand, and walls are formed, dividing up the original cell into four separate chambers. Each of these spores is capable of 'budding' from any point of its surface as the parent-cell did, so that the yeast plant has now developed four-fold, and each of the four daughter-cells, now swollen up, can 'bud' and bring forth a new individual.

This is a typical case of asexual generation in which one cell is strictly sufficient for reproduction whether by division of its substance or by the formation of spores. A little further up the scale we find two cells, apparently exactly similar in substance, uniting and fusing their protoplasm with the object of producing a new plant. In one of the algæ (Spirogyra longata) which consists of long green filaments composed of cells placed end to end, two filaments, as they sway and move in the water which is their home, become parallel one with another and cling closely together; soon protuberances begin to grow out from the walls of two cells brought into juxtaposition; they meet and the cell-wall between them dissolves so that the way is open. Meanwhile the protoplasm of each cell, which in ordinary circumstances lies around the nucleus and contains the spiral bands of chlorophyll, contracts and forms a rounded mass. Now, however, a difference of behaviour between the two cells is seen; the one remains stationary and makes no sign; the other puts out feelers of protoplasm like long threads which presently reach and touch the mass of protoplasm in the other cell. As soon as this happens the whole of the protoplasmic contents of the searching cell glide over and fuse with the stationary one. There is complete union. Even the spiral bands of chlorophyll in the two cells join ends and become one, and there is no token whatever of the presence of two individuals within one cell; the one has simply absorbed the other and there is no trace! The composite body thus formed surrounds itself with a cell-wall, rests at the bottom of the water until the next spring, when it rises and germinates, developing into a new plant with long green filaments like the parent.

It is always intensely interesting to trace the beginnings or foreshadowings of a great principle of life, and here we clearly recognize the early manifestation of that co-operation of two separate cells for a great end—the reproduction of their kind. In this case there is no apparent difference between the two; to all appearance they are exactly alike, and after fusion they are one, and at first—strangely enough—apparently unchanged and like either cell before the fusion! Yet obviously there is a difference. One receives in order that, receiving, it may give, and bring to birth a new being; the other gives unreservedly all that it had, that it may find its life in the life to be. Here are the beginnings of the two specialized reproductive cells, and though the asexual method may go on side by side—even in the same plant—with this co-operative or sexual one, yet the latter has come to stay and to manifest itself more and more perfectly through an endless succession of varying modes and modifications, till in the highest plants it is perfected into a beauty of detail and of imaginative thoughtfulness which seems to absorb the whole spirit of the plant, and calls forth our wonder and admiration.

We must remember that the trust of the inherited germ-plasm has been committed to each of these two cells in part, and that neither can fulfil that which is committed to it without the other. This must somehow be at the root of the strange affinity of the one kind of cell for its partner. One thinks of chemical affinity and of the call of the positive electrical charge in the one element for the negative electrons in the other, and one wonders if some such physical basis of attraction lies deep in their being. However this may be, it is certain that the call is strong and far-reaching, and the two partners find each other in many and romantic ways.

Usually the male cell is extremely small in comparison with the female, and when we consider that it is only a portion of the nucleus of the minute male cell which contains the precious trust and goes to join with some portion of the nucleus of the female—both in many cases microscopically small—one realizes afresh the power of the infinitely little, and one remembers that 'great' and 'small' are words appropriate only to our finite condition but not to be taken as having meaning in ultimate views.

In this strange world in which we live it seems to be the rule of all rules that no rule is without exception, and when in the course of our observation of the sexual methods of reproduction we think we have discovered laws which bear on the meaning of this special co-operation, we are apt to be met with startling facts which warn us to be careful how we generalize!

It has been thought—and doubtless generally with reason—that there is advantage in the crossing of the male organ's vital cells belonging to one plant with the female's of another, but in certain cases, the violet and some forms of viola for instance, the ordinary sweet scented or beautifully coloured flower is usually barren, whilst little hidden flowers produced amongst the roots and lower leaves and undiscovered by insects, have special arrangements for self-fertilization and produce all the seed!

Again, it is naturally supposed that where plants are clearly divided into 'male' and 'female', the latter have no power to produce seed without the male, yet astounding examples of apogamy discovered by De Bary reveal certain ferns and a highly developed alga which have this power. In the case of the latter (Alga Chara crinita) Sachs tells us that " this plant which lives at the bottom of stagnant water, is met with throughout the whole of North Europe exclusively as female individuals, which however, and thus without fertilization, yield abundant and normal germinating fruits." It seems probable that these cases were originally sexually producing plants, and that they have gradually reverted to the asexual habit. Yet it is difficult to see that they are any the worse, and they are certainly not dying out. The advantages of the co-operative method are more or less obvious: it seems less likely that injurious abnormal developments or diseases should be propagated where there are two elements—and one presumably a normal and healthy one—involved in the process. On the other hand a door is undoubtedly opened to new and healthy variations and mutations. Sachs considers that in general the highest development of the organism is obtained as a result of fertilization, and I think we may take it that this is the main fact, however liable in certain cases to exception.

It is not my intention in this chapter to describe the extraordinarily interesting series of methods of reproduction in the various classes of plants from the lowest forms of algæ to the flowering Angiosperms of our gardens and fields. In the following chapter which deals with the distinctions between plant and animal and their slow differentiation the one from the other in their early beginnings, I shall have to return to this subject from another point of view. But for the present I propose to pass on to the consideration of the response to the second command of the Life-Force in some of the most highly developed plants in the present stage of existence. It is hardly necessary for me to explain that in these flowers the male cells are found in the pollen of the stamens and the female in the ovules waiting for fertilization at the bottom of the pistil. In order that the former should reach the latter not only must there usually be a journey on the wings of the wind or borne on the body of insect carrier, but when at last the spot is reached which roofs in the waiting ovule, the small

FIG. 20—The Common Daisy.

voyager has yet a further and more personal effort to make in his penetration through the soft tissue of the stigma which receives him, down the style or stalk of the pistil to the ovary, where he finds a minute entrance to the co-operating cell of the ovule, and at last his bourne is reached. This will be a little further explained in the next chapter. In telling the story of the development of these highly organized flowering plants, to which the general name of Angiosperms has been given from Greek words signifying 'receptacle' and 'seeds', in distinction to Gymnosperms or 'naked-seeded', it has occurred to me that an appropriate title would be "From buttercup to daisy", for, strangely enough, these two closely associated flowers of our childhood stand as types of the lowest and simplest and of the highest and most developed of the flowering plants. It may be remembered that in the third chapter of this book I used the buttercup as a typical early flower with all its parts separate and simple in form, from which to gauge the amount of work done by the Life-Force upon any other plant under consideration, and its consequent place in evolution.

Now if we compare the common daisy of the lawn or field with the buttercup, we shall quickly see that they are indeed worlds apart! As most of my readers doubtless know, the daisy is not one flower but a group of wee florets surrounded by an involucre of bracts which answer to the calyx of an ordinary flower. Examining these golden florets which form the daisy's centre and comparing them with the buttercup we find very great changes of arrangement. The calyx is merely represented by the short downy hairs of the pappus—which in the dandelion grows up to form the round head of downy parachutes, called by children "the clock"; the petals of the corolla have all grown together into a little tubular flower with five teeth. Inside this are the five stamens with anthers joined at their tips into a tube, and far below lies the ovary with its single ovule and its style and stigma passing up the centre of the tubular floret.

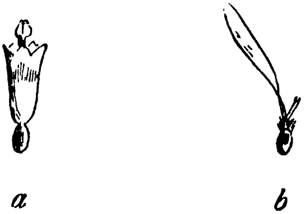


FIG. 21—*a* Inner and *b* outer florets of the Daisy community.

The highly organized family of Compositæ to which the daisy belongs is an extraordinarily successful one and its members are said to constitute about one-tenth of all known plants. It is to be found in almost every part of the globe. As a rule the Compositæ do not seem to be of any special service to man, and some of our worst and most troublesome weeds belong to this great family as well as our beloved little daisy which is believed to have come into the world at about the same time that man first appeared.

Thistle and burdock, dandelion and hawkweed, groundsel and ragwort, yarrow and tansy all belong to various orders of this group, as well as a few more attractive flowers, such as the cornflower and marigold, golden-rod and aster tripolium—our native Michaelmas daisy.

We shall naturally seek for the cause of their world-wide prosperity, and ask why they should be specially blessed by the Life-Force, and apparently stand in the direct line of evolution. As workers they seem honest and above-board; I do not know of any parasites amongst them, nor have they, apparently, turned aside after strange methods of securing sustenance like the carnivorous plants. Neither have they entered into pact with any of the lower members of the plant-world. They are not, as a class, specially endowed with powers of response to stimulus or surprising movements, like some groups of which I shall speak later. In fact they seem to be just hard-working, honest, and frugal plants, living faithfully and contentedly in varied and often poor surroundings and surviving where others fail to make a living. What have they brought to woo success and how have they fulfilled the great commands?

It appears that their riches have consisted in two principles faithfully and simply carried out in their response to the second great command.

The flowers of this family were very small and little able, by their scent or colour, to attract insects whose visits they needed for the fertilization of their ovules. But if grouped together so closely as to form one head on a single stalk, with a single floor, walled in by a close-set involucre of green bracts (leaves attending on the flowers), the double advantage was secured of economy for the plant and greatly increased attractiveness for the flowers. Insects which would have passed by the minute single florets were quickly drawn to the communities of crowded flowers which often displayed around their margin a ring of broad strap-shaped leaves of gold or silver or purple, as in the sunflower, the common daisy, and the purple aster. In this collective gathering of the florets the principle of co-operation is very obvious.

The central florets in these communities of flowers are in a large number of cases tube-shaped with their five stamens joined in a ring, and one little ovule in the nursery below as described above. It is a very highly developed form and has come far along the road of evolution. The outer ray-florets have made the sacrifice of fertility for the sake of the rest of the community and are for the most part barren, though they may still possess the sexual organs. It is a true co-operation of member with member for the good of all and wonderfully carried out to the last detail, no individual daring to say that anything he possesses is his own, nor hesitating to sacrifice his most sacred hopes if called upon for the good of the rest. Not even the pollen manufactured within the golden tube of the central florets (I am describing the daisy more particularly) belongs to the manufacturer himself; that is carefully provided against. The anthers of the golden ring within the tube ripen early and shed their gold dust, filling the floret's little cup. But the ovule is still asleep below, and the receptive surface on which the pollen should fall is not ready, and the style or stalk of the pistil with the closed stigma at its tip lurks still ungrown at the bottom of the tube. When the pollen is all shed the style begins to grow, and with its brush-like tip it pushes the masses of pollen in front of it out of the tube, exactly in the way a sweep would clear the soot from a chimney. Out flies the pollen to dust the legs and bodies of insects, who bear it to bless other little florets whose time of ripening was slightly earlier and whose ovules are awake and expectant. Then at last, when the gold dust is all scattered, the brush-like stigma separates into two branches, exposing the receptive surfaces which hitherto have been pressed together like the palms of two hands. Now the co-operation reaches further than the separate community and one group of florets calls to another and the gold dust circulates, and up and down the countryside the principles of co-operation and of sacrifice are being joyfully expressed by the thronging white daisies as they prepare to fulfil the second great duty imposed upon them by the Life-Force.

Methods may vary in the vast army of Compositæ, but the general principles of co-operation and of sacrifice are the same. In the thistles the florets are all tubular and red or purple, and, as we have too good cause to know, the seeds when ripe are each provided with a feathery pappus like a parachute wherewith they go off on the wings of the wind to seek their fortune —a most successful device! The strap-shaped dandelion florets have the same method and it is a common one amongst the Compositæ. The daisy, however, and some others do not possess it for practical purposes, though there is often a minute ring of pappus hairs. Nevertheless they are as widely distributed as any.

In our little daisy and the plants belonging to its special group amongst the Compositæ, it is generally agreed that we reach the highest point in the evolution of the flowering plant. There are of course far more striking and remarkable flowers, more spectacular instances of adaptations both in form and function, but in the true line of evolution the daisy group is—as has been said of the sunflower—"as near an approximation to the typical Angiosperm (the higher of the two great orders of flowering plants) as can perhaps be obtained."

Once more we must return for a few moments to the principle of phyllotaxis and look at our little daisy from this point of view. If you will gather a specimen that has passed its youth and is beginning to shed its ray-florets, we shall be able to examine this community of wee flowers with greater ease than in a young specimen. Removing the remainder of the ray-florets we find a conical hill set round with a ring fence. The hill is crowded from base to its extraordinarily pointed summit with minute tubular flowers so closely set that they form a solid phalanx and entirely clothe their fortressed eminence. Looking through a magnifying glass one easily sees that they stand in an ordered array, and that spiral curves may be detected, as on the fir-cone, some running to the right and others to the left. There are thirteen running one way and twenty-one the other, and if one counts the bracts which form the green ring fence one finds invariably that there are thirteen of them. Their phyllotaxian number according to this will be $\frac{13}{34}$ and the central invisible coil will have to pass 34 minute florets before it finds one exactly above its starting point. The giant sunflower, which belongs to the same group as our little daisy, presents to us in his great head of ripened seeds set in a golden ring of rays perhaps the most wonderful phyllotaxian pattern that is to be found in the plant world. Practically it is like a fir-cone flattened out into a circular plate. Spirals curving from the centre run in either direction, crossing with beautiful precision and entrancing effect. In some heads the number of spirals running one way will be 34, and in the other direction 55, which means a phyllotaxian series of $\frac{34}{89}$ and the central coil would have to pass 89 seeds before it found one placed exactly above the starting point. In the very large heads as many as 89 curves in one direction and 144 in the other have been counted, involving a phyllotaxian series of $\frac{89}{233}$. These are impressive numbers, but great or small, the wonder and perfection of both form and order in these community-plants are the same. More and more one is led to see that nothing is without meaning and a place—open or secret—in the great hidden spiral of creation; but here and there the secret seems to break through and come for a moment into at least partial view, and we are struck with wonder and a sort of deep joy.

Without too great fancifulness I think we may imagine the little florets on the summit of the conical hill of the daisy gazing with grave eyes down the long path of evolution up which they have travelled, as they stand at the 'growing point', so to speak, and some old words seem to ring in our ears as somehow appropriate: "a little one shall become a thousand and a small one a strong nation."

CHAPTER VII

MOTILITY IN THE PLANT WORLD
THE PLANT AND THE ANIMAL

HITHERTO we have watched the results following on the urging of the Life-Force in the vegetable world, and have studied the responses made in certain selected cases and groups. It has become clear that in some degree a choice of ways is open, and that at critical moments plants of a certain group or family may make a decisive move for good or ill, and this may start an upward or downward course for their descendants. We have followed one or two such adventures and have seen where they led, and by our judgment on the result have been able to gain some glimpses of the true aim of the silent Life-Force, and to realize certain principles which seem to lie behind its working.

It has become perfectly clear that at a very early stage in the world history the minute children of life in specks of living protoplasm broke into two groups, responding each in its chosen way to the urge of the Life-Force. The one elected to remain unenclosed and free, open to every stimulus of its environment, to every deadly assault or tender wooing—a great adventure, surely! This was the future animal. The other enclosed its precious life substance within a stout ring-fence of cellulose, and was the forerunner of the vegetable kingdom. At that very early stage the two were practically indistinguishable, for such changes as these, intensely important though they be and inconceivably wide as may be their consequences, are slow and indistinct in their beginnings. And even in the present day botanists and zoologists have fought fiercely over many of the microscopic beings which exist in unseen millions in water, earth, air, and in the bodies of other plants and animals, each observer claiming them for his own kingdom.

It may be deeply interesting, and also helpful in understanding the way of working of the Life-Force, if we try to see how far the vegetable, in spite of its fateful choice, has remained open to the touch of its surroundings, what possibilities of response are yet within its being, what choices are still open to it by its inherent opportunities, and what degree of responsiveness has been attained by its most highly developed representatives. For this purpose it will be best to study first the beginnings of animal and vegetable life, though in a very cursory way, in order to realize the extraordinary amount of interweaving of their nature which even now persists in the lowest forms. We do love to classify, and we love to have everything perfectly clear and distinct—and Nature will not have it so, for freedom from the letter of the law and faithfulness to its spirit is her unchanging principle. So we are baffled at every attempt to make a sweeping definition which will describe without exception the groups of living things that we want to classify. "Nature" writes John Lightfoot, *Flora Scotica* II, 1777, "disdains to be limited to the systematic rules of human invention. She never makes any sudden starts from one class or genus to another, but is regularly progressive in all her works, uniting the various links in the chain of beings by insensible connections." "The vegetable cell is enclosed", we say dogmatically. But before the eyes of the investigators with the microscope, little naked vegetable cells, moving like animals, go out from the parent plant and seek their fortune in the great world. "The vegetable is fixed and stationary" it used to be said, but this theory with our newer knowledge is broken and valueless.

Let me try to tell the story of one or two amongst the endless variety of methods by which in the lowest plants the commandment is obeyed to hand on the life committed to them. Of course every class of plant is different and works in its own special method, and the variety is enormous and the subject very complicated and full of wonder, but these examples will shew how life breaks through our theories and classifications, and scatters our preconceived ideas.

At the very bottom of the scale of being, reproduction is frankly by division of the single cell composing the plant into two equal parts, which speedily grow to the original size of their parent. But, still at a very early stage of evolution, special cells begin to be set apart for the duty of reproduction. Amongst the lowest of these a single cell may, alone and unaided, accomplish this work. In the group that I have in mind some of the members are still only one-celled, but this single cell is large, tubular, green in colour, and much branched, and it has a colourless part which answers to a root. The whole of the body, however, is undivided by cell walls—so it consists of one big cell. These plants are called Vaucheria, and are a kind of water weed forming dark green patches on damp soil or in springs or wells. Others have more than one cell, these being arranged end to end, so that a row of them forms a filament or long thread. Examples of the latter class are the Œdogoniæ, water weeds like the Vaucheria.

In the case of the Vaucheria, preparation is made by a portion of the general big cell being cut off by a dividing wall. Out of this specialized cell, in process of time, comes forth a little speck of jelly-like protoplasm, naked, defenceless, and exceedingly minute, but a wonderful speck of matter nevertheless, for this is indeed a new being and its coming forth is a birth. It has no firm wall round its delicate substance as yet, but has fine hair-like filaments, called cilia, by means of which it can move through the water like an animal. After a time this little body, called a zoöspore, comes to rest; the adventure of its birth voyage is over, a cell wall is formed around it, and it begins to grow into a new plant like its parent, developing branches and the colourless part answering to a root. In due course it, too, will prepare a specialized mother-cell, and give birth to another little voyager, who will go through the same short, but thrilling adventure before he settles down within his wall.

In the case of the Œdogoniæ with the filaments of cells arranged end to end, one of the ways of reproduction is for a particular cell to prepare itself in a special way, the jelly-like content contracting and seeming to draw together inside its wall. Then wonderful changes go on in this speck of protoplasm till at last it is, as it were, re-born and made young and new. Then it comes out of its cell—a zoöspore with little cilia like the one I have described—and swims about happily till the resting time comes, when it settles down and grows a cell wall and is a new individual.

Compare the two above cases with the early history of the oyster. Every mother oyster is capable of producing a million or more eggs every time she spawns. These eggs are fertilized within the body of the female and are hatched within the sheltering shell-valves of the parent. There they pass through the very earliest stages of their development, until—a week or ten days after hatching—the doors are open and they issue forth, a crowd of minute, shelled larvæ, so small that they have been likened to the grey dust obtained when a slate pencil is sharpened, for their great adventure. Now they swim about like the little zoöspores, provided like the latter with a crown of rapidly moving cilia which can be projected at will from between the open valves of their shell.

Critical indeed is this free stage of their life—so transient, yet fraught with such possibilities and dangers. For if the wee adventurer cannot find a firm, clean substance to which he may adhere, he is doomed. Mud or slimy stones are not a suitable surface, and the baby oyster which finds nothing better inevitably dies at the end of a few days. Oyster cultivators well know this, and in some of the great oyster parks in France, roofing tiles coated with sand and lime are provided, and when " the spat falls " as the cultivators say, the minute oysters attach themselves to these and almost immediately change in structure and form until they resemble the parent in all but size. Henceforth, their swimming days of freedom are at an end and they are as fixed as are most vegetables.

One does not need to press the likeness between the two cases, or its bearing on the difficulties of dividing betwixt plant and animal on the ground of motility, or of surrounding cell-walls. But it is not only in the lowest forms of plant life that these characteristics are to be found, and before discussing other specialities—supposed or real—of the vegetable as distinguished from the animal, I must pass on to examples of motility and naked cells in much higher plants.

We have spoken of single cells specialized for reproduction, and giving birth to tiny moving bodies called zoöspores. But " spores ", or seeds developed from single cells in the lower plants, are not all gifted with the power of movement, nor do they all immediately develop into new beings like their parents. Looking on the back-side of the fronds of many kinds of ferns we find brown patches on some of them which, if examined through a strong magnifying glass, will be found to consist of fine powder or dust. The separate grains of this powder are spores, but not motile ones. When they fall upon the damp ground, instead of each growing into a fern, like the one which produced them, they each develop into a flat green growth, rather like a lichen, and generally heart-shaped. Upon this heart-shaped flat growth, which has hair-like roots and clings to the earth, presently two different kinds of grouped cells appear. The one set are usually rounded or egg-shaped; the outside cells of this group form a wall to protect the precious inner ones, each of which contains a curious little cell like a spirally wound thread, furnished with cilia by means of which it can move through moisture like a zoöspore. These little moving naked cells are called antherozoids and their romantic duty is to go and seek the cells within the *second* set of which I spoke above, which are to co-operate with them to form a fern like the original one whose brown powder fell on the earth. This second kind of grouped cells is flask-shaped, the neck of the flask being formed of cells acting as protectors, and the cell that is to co-operate, which, like the antherozoid, is unenclosed by a wall, lies safely ensconced at the bottom. Here, in the flask-shaped cradle, the new little fern takes its beginning from the union of the two parent-cells, and one may see its first baby frond arising out of the flat green growth, called a prothallium, which was the first product of the brown spore.

This is spoken of as the "alternation of generations" in ferns and mosses, etc., because only the second generation, so to speak, is like its parent. This fact is hidden as we pass on to the flowering plants, yet it nevertheless exists, though the strange 'unlike' generation never sees the light.

A little higher up, but closely connected with ferns, are certain plants—mostly water weeds—which bear two kinds of spores, big ones and little ones. The big ones, or macrospores, produce within themselves a sort of growth which answers to the flat green prothallium of the fern spores, but upon this growth the flask-shaped groups of cells alone are formed. The little spores, or microspores, for their part, hardly bother to make a prothallium at all, but after a little cell-division has gone on, they produce small motile bodies of the same nature as those produced on the prothallium of the ferns. These antherozoids go to find the cell in the flask-shaped organ formed by the macrospore, and co-operate with it. So in these plants, instead of *one* kind of spore producing a prothallium with *two* kinds of cells, two kinds of spores each produce one of the two kinds of cells, and specialization has gone a little further. The advantage of two separate *beings* co-operating is beginning to be shadowed forth, and it is easy to pass on in thought to the flowering plants, and to connect the pollen-grains of the stamens with the microspores. But by the time evolution has proceeded so far as to produce flowering plants, the cells of both co-operators have become enclosed, and there is no more joyous swimming of the antherozoid to seek his partner. Instead of this, the wind or the friendly insect must bear the pollen grain to the stigma of the flower that is waiting for him. Upon its moist surface the grain of golden pollen consisting of four cells soon protrudes a tube which is an outgrowth from the largest of the cells, and which consists of the protoplasm of the cell *still covered with its inner wall*, though the outer one is broken through. This tube grows down through the style to the waiting ovule with which it co-operates to form the seed.

Here we have passed beyond that early motility and freedom that persisted for so long at some stage in the life of the vegetable, and there is no longer any difficulty in distinguishing it on these grounds from the animal.

Turning back to the earliest plant forms we ask if there were not other marks by which they could, from the first, be distinguished from animals. One there is indeed, which not only appears most clearly and definitely to separate the two forms of life, but also gives us a satisfying and convincing reason for the evident blessing of the Life-Force bestowed upon *both* choosers in that early day when animal and vegetable began to diverge. Though the latter appears to have taken the lower course, yet the Life-

Force had surely a special blessing for its work of service and sacrifice, and the glorious gift to the plant is the power to draw from the inorganic sources of nature supplies which the animal is powerless to obtain for itself, and in the laboratory of its green vegetable cells, by the aid of those mysterious chlorophyll granules and in the presence of sunlight, to prepare these substances for the assimilation of plant and animal life. By the sacrifice of its own body it must feed the animal, yet never can it reach the heights of conscious life, mental, moral, and spiritual, to which the latter is destined.

A kind of grateful reverence springs up in one's heart as one dwells on this thought and realizes all its implications. One is led vividly to unify oneself with all creation and to visualize one's dependent position therein.

This third mark of the vegetable, the power to prepare food from the inorganic, seems a fairly sure and clear one, but at the bottom of the scale there are ambiguities even here. It is apparently only in the presence of chlorophyll that such preparation can be accomplished, and animals usually have no chlorophyll. But, as we learn from Professor Sachs, a number of undoubted animals of the lower forms have been found to contain chlorophyll by which apparently they could assimilate inorganic matter. Professor Ray Lankester has drawn up a considerable list of such creatures, and the confusion between plant and animal must have seemed worse than ever until the startling discovery was made that the chlorophyll is contained in *vegetable cells within the body of the animal!* Paying guests again, one must suppose! We remember that the guests of the Leguminosæ, said to be fungi, and without chlorophyll, yet appeared to be able to do what fungi as a rule are incapable of doing and to assimilate inorganic food in the shape of nitrogen drawn from the air. But this may be through the chlorophyll cells of the host-plant.

To say the least of it these distinctive marks are very elusive, and various others, which were at one time thought to be conclusive, have now entirely broken down. Edward Clodd, in his *Story of Creation*, even states that "there are organisms which appear to be plants at one stage of their growth, and animals at another stage", and we can scarcely wonder at Professor Huxley's remark that "the problem whether in a given case an organism is an animal or plant may be essentially insoluble."

All the above only goes to prove that the step taken by the vegetable cell in enclosing itself within its wall was a very gradual one, which is no more than we might expect from what we know of the methods of the Life-Force. The loss of chlorophyll in the animal cell seems to have followed or to have begun simultaneously, and the dependent position of animal upon the vegetable would then be a natural result.

The question which now interests us is that of the present power of response in the plant and its ultimate possibilities.

That there *is* response to its environment and to all the forces and various stimuli that surround it we have a hundred demonstrations. We watch the flowers and leaves turn to the sun, the young shoot and tendrils of the climbing plant 'feel' for their support and cling

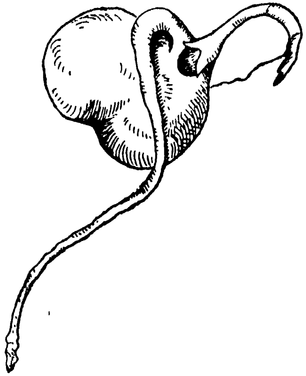
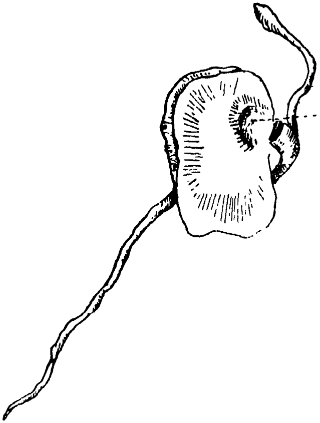


FIG. 22—Germinating pea to shew the shoot growing up to light and air and radicle finding its way down into the earth.



Also cut in half shewing the depression where the head of the plumule rested, *a*.

when they find it; the tiny shoot of the seedling grows up to the light and air, whilst the wee radicle wriggles its way down into the earth, the petals of flowers close in rain to protect their stamens and pistil at an important moment, and leaves of seedlings and of many adult plants fold at night; we see a green shoot or flowering stem of a plant in spring, beaten down by a rough wind, rear its head and lift itself on its elbow, so to speak, as if called by a voice from above, and we may observe the little copper-brown-leafed oxalis or the yellow wild balsam (Impatiens) or touch-me-not under the influence of a hot sun or some chance touch suddenly relax the tension of their ripe seed pods and shoot forth their seeds with surprising force and unexpectedness. These are common and everyday sights which one takes for granted without special remark, yet they are undoubtedly direct responses of the plants to their environment and to the various stimuli that act upon them.

Certain other more unusual cases startle us into attention, and we think that they represent something new and unprecedented in the power of response in the plant world. The stamens of the common barberry, which at a light touch spring forward from the petal of the flower against which they are pressed, to clasp the ovary and discharge their pollen, and those of some of the Centaurea, specially the knapweeds, which, when touched by bee or by the pencil of the observer, will often wave to and fro and discharge the pollen from their purple tubes—these by their visible movements give us the impression of a spontaneous and conscious action like that of an animal.

Still more remarkable is the quick response of the 'sensitive plant', so-called, (Mimosa pudica) and of its sister, Mimosa sensitiva, whose rows of leaflets forming their compound leaves seem to shrink at a touch, fold together, and finally, if further disturbed, hang down by the bending of the main leaf-stalk at the point of its union with the stem, as if frightened and fainting.

Even the galloping of a horse in their neighbourhood, through the vibration of the ground, may cause them rapidly to take this position, and it is said that where these plants used to grow abundantly by the sides of the Panama Railway they were observed to fold up their leaves when a train passed. The Mimosa belongs to the family of Leguminosæ, of whose way of life we have made some study in a former chapter, and many of this family are 'sensitive' or appear to have unusual powers of response and of automatic movement. The most remarkable and best known of the latter is the 'telegraph plant' or moving Sainfoin, called by the Hindoos—for it is a native of the plain of the Ganges—'Bon Charal' or Forest Churl or outcast. It is supposed by them to dance to the clapping of hands, but as a matter of fact its curious motion is almost continuous and without apparent cause. Its proper name is Desmodium gyrans, and the first name denotes the genus which belongs to the sub-tribe Hedysariæ, so that it is sometimes called Hedysarus gyrans. Like so many of the leguminous family it has compound leaves; there are only three leaflets in this species and the middle one is large whilst the two side ones are extremely small. The latter keep up a curious rhythmic up and down movement which is not unlike the rhythmic beat of the heart. The up movement is slow; it may take from one minute to one-and-a-half minutes; then there is an apparent pause, and the quicker down movement may be executed in about forty-two seconds. In hot weather the time is shorter, and in the cold season it is longer.

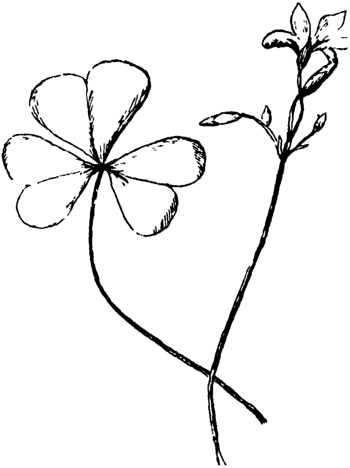


Fig. 23—Day position Wood Sorrel and Oxalis.

Very naturally these 'sensitive' and 'moving' plants have attracted the attention of ordinary travellers as well as of naturalists, and the impression is left on the mind of something out of the usual order of nature, pointing possibly to spontaneous movement in the plant. But, as one has been led to feel in the case of the fir-cone with its wonderful array of ordered numbers, these startling effects in natural things are usually only the outcropping at the surface of the continuous work of the Life-Force along certain lines, and it is almost certainly a mistake in any given case to suppose the fact observed to be detached and peculiar.

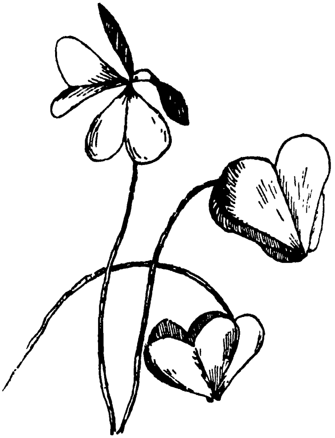


FIG. 24—Wood Sorrel and Oxalis.
Night position.

Besides the plants I have spoken of there are many less known plants with some degree of this specially noticeable ‘sensitiveness’. The leguminous family produces several, and the Oxalis family has others amongst its members. Biophytum sensitivum belonging to the Oxalidaciæ has leaflets which in special conditions shew a power of so-called spontaneous movement like the telegraph plant. Oxalis stricta, Oxalis sensitiva, and Averrhoea bilimbi of the same order, might be mentioned with many others, but a mere list of names would be of little interest.

To come nearer home to a case which it is possible for us to observe for ourselves: our own little wood sorrel (Oxalis acetosella) with clover-like leaves and a delicate white or lilac flower veined with purple, has a considerable degree of 'sensitiveness' and even of motion without visible cause. At night the three leaflets fold together inwards and hang down like a closed umbrella, and this position is also taken under the influence of a hot sun acting directly upon them, also when subjected to the shock of uprooting and replanting, etc. They are said to fall and fold at a blow with a stick as do the leaves of Oxalis stricta and Oxalis sensitiva. But beyond this visible response to stimuli from the outer world they seem to have the power of re-acting to causes hidden in their own physical being, and Prantl & Vines, in their text-book of Botany say: "these leaves possess also a periodic motion, effected by internal causes, which only becomes evident when the plants are kept for some time in continuous darkness: it is then seen that the leaves are in constant though not very vigorous movement. It appears, therefore, that exposure to light tends to arrest the spontaneous movements, and to cause the leaves to take up the diurnal position" (that is to expand in their normal way).[1] Professor Morren who has made some studies on this and other of the Oxalis family made some observations which finally led to the very unexpected discovery of some analogy between the structure of the leaves of the wood sorrels and those of the Mimosa. This links together the two families of Leguminosæ and Oxalidaceæ, and suggests a cause for the finding of a large number of plants with 'sensitiveness' to touch or automatic motion in these families.

We must not, of course, imagine that it is only in the families of Leguminosæ and Oxalidaceæ that noticeable movements or response take place. I may recall to our memory the sundews and pinguiculas of our bogs and Venus's Flytrap of North Carolina, of which we made a study in a former chapter. In these cases the 'irritability' of the special glands of the leaf is adapted to a special purpose of usefulness and has undoubtedly been perfected by natural selection. But it is a very clear and striking example of sensitiveness to touch, combined in these cases with a wonderful discrimination as to the substance that is in contact with the tentacles or glands, for it must be here remarked that a bit of inorganic matter finds the leaf wholly unresponsive.

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[1] In connection with this statement I quote a remark of Sir J. C. Bose: " Light appears in some cases", he says, " to initiate movement . . . and in others to arrest it, as is said to happen with the spontaneous movements of Trifolium pratense." He quotes other examples of apparently varying effect of light on plants, and concludes " We thus see that not a single responsive effect of light has been observed in the case of plant-organs of which an example directly to the contrary may not be found. For this reason it has appeared hopeless to attempt to unify these phenomena, and this fact has left investigators with little option but to tend towards a 'belief in the individuality of the plant in deciding what shall be the effect on it of external conditions' (Francis Darwin)."

From this conclusion Sir J. C. Bose revolts, as might be expected, from his consistent view of the plant as a machine, and he proceeds to put forward his own theories, based on his very searching mechanistic investigations, to explain this most intricate problem. This must be referred to in the next chapter.

We have already spoken of the sensitive stamens of common berberis and of the knapweed, and the pistils of certain of the Scrophulariaceæ are said to be ‘ irritable ’, but indeed in a greater or lesser degree this character of visible response is far more widely distributed than is generally supposed, as is also that of automatic movement, which may be seen as well in the Oscillatoria—a genus of lowly water weeds—with their oscillating filaments as in Desmodium gyrans, belonging to the highly developed Leguminosæ, with its pulsing leaflets.

Yet there are certainly a very large number of plants which shew no visible response to touch or irritation, nor have they any apparent automatic movements, periodic or otherwise. Are these truly without response, and if so, what causes the difference between them and their more sensitive fellows?

Much light has been thrown on this subject by the long-continued and very delicate experiments carried on by Sir Jagadis Chunder Bose, an Indian professor who has devoted many years to the minute study of responsive and of automatic movement in plants. With incredible skill and ingenuity he has invented a wonderful machinery to assist him in this delicate work, and has filled many large volumes with detailed accounts of experiments and deductions drawn from the latter. Using the visibly 'sensitive' plants and those exhibiting natural automatic movements as a base of operations, he had found means to test the secret response to stimulus of those plants which are unable to exhibit it openly, and has explained the mechanical difficulties which stand in their way. Though his wide generalizations have not been accepted at present by most botanists yet his pioneering work in these experiments is most inspiring and suggestive, and must eventually lead, by stimulating research on these debatable points, to a deeper knowledge of the physiology of plant life and its capabilities of responsive movement. It will be worth while to go into some of his theories and to get a view of his position in the great questions to which he has devoted so much time and effort. This I propose to do in the next chapter.

Meanwhile I append a few suggestions for experiments which can be made by any ordinary person on certain sensitive and mobile leaves, with an account of some rather interesting ones made by myself on quite common leaves.

PRACTICAL EXPERIMENTS

It will assuredly be a very great help to our grasp and realization of the fact of response to stimulus in plants if we can make some observations on our own account, and fortunately there are certain plants obtainable by most people, which demonstrate this point in a surprising way if we know how to put the question to them.

The acacia tree (so-called, but properly speaking Robinia) with its white laburnum-like blossoms, is one of the best. Gather a leaf which is neither young nor very old, remove the thickened part of the leaf stalk where it joined the stem (called the pulvinus or cushion) and put the leaf in water, where it will be best to leave it quietly for a night. Next morning, having placed the leaf in water in a small bottle so that you can keep it upright with all the leaflets free, stand it against some kind of background upon which you can make lines or marks to note the exact position of a leaflet. Choose a leaflet in the middle of the leaf and make a scratch with a pin across the back of the very short stalk or petiole which joins it to the main stem of the leaf. If you prefer you can nip the petiole between your thumb and second finger nails, but let your nip be strongest at the back or under-side, and be careful not to nip off the leaflet, which is easily done by accident. Now watch carefully against the background and you will see the leaflet slowly move backwards and fall from its natural daytime position, which is horizontal to the main leaf stalk, to its night position bent back as if drooping. Very probably the leaflet next to it will be affected by the shock in like manner, and I have frequently seen several leaflets, either above, below, or opposite to the irritated one, fall, as the effect of the disturbance reaches them. Irritation by a scratch or nip of the *main* leaf stalk will cause the fall of leaflets both above and below and is often very effective. A scratch on the *front* side of the petiole of a leaflet will *sometimes* cause the leaf to rise up instead of falling back, and to stand above the rest, but this does not often happen I find, the under-side of the stem and petioles being by far the more sensitive. I made my experiments on Robinia in warm July weather when the thermometer in the room stood at from 66° to 70° F., and in cold weather, later in the year I think the leaves would probably be less sensitive. They vary more or less according to the time of day and I generally found them more sensitive in the morning. The

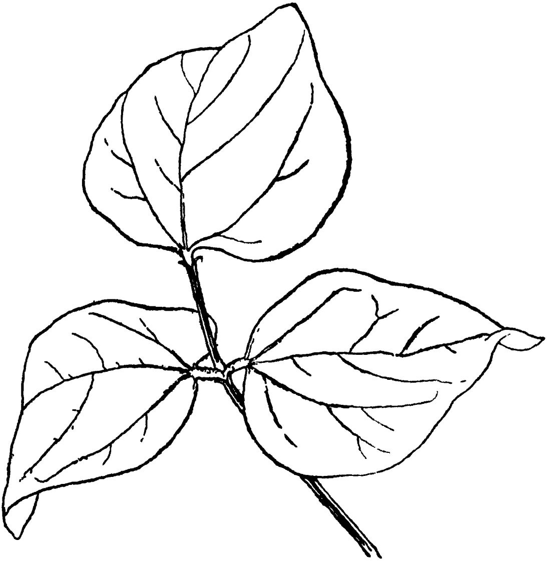

FIG. 25—Scarlet Runner Bean leaf, day position.

Wistaria is, I think, nearly as sensitive as the Robinia if fairly young leaves are chosen.

Another plant which almost everyone can obtain in summer is the scarlet-runner bean.

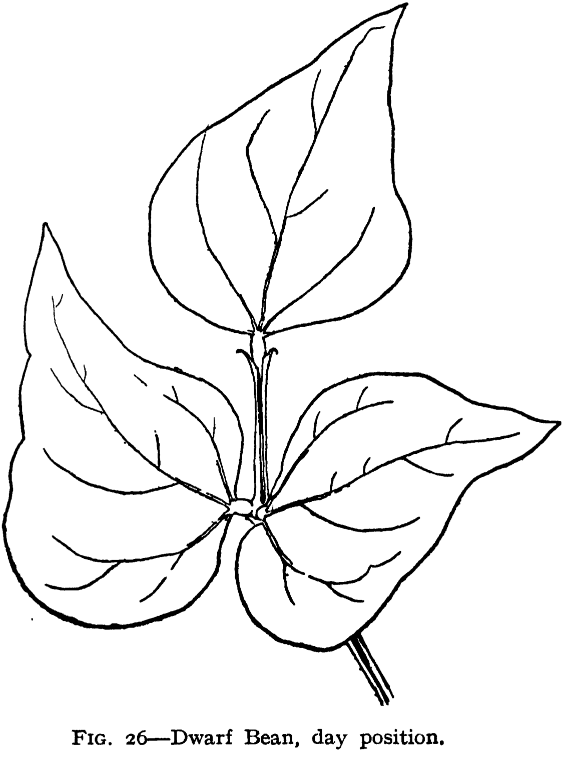

FIG. 26—Dwarf Bean, day position.

A leaf of this plant will answer our purpose almost as well as the Robinia. It has three leaflets, the terminal one on a long petiole, which ends in a short, softer, and quite distinct portion called a pulvinule or little pulvinus, and the two side ones on short pulvinules with no petioles. Their natural position in the daytime is with the terminal leaflet well erected and the two side ones held horizontally; at night all three leaflets, but more especially the terminal one, bend downward as if drooping, the petiole and pulvinules remaining more or less erected, and leaflets drooping from the 'hinge' so to speak. In the dwarf runner bean, which is, I think, still more sensitive, the petiole and pulvinules themselves bend down at night and the two side leaflets often curve round and seem to creep underneath the terminal one which bends broodingly over them.

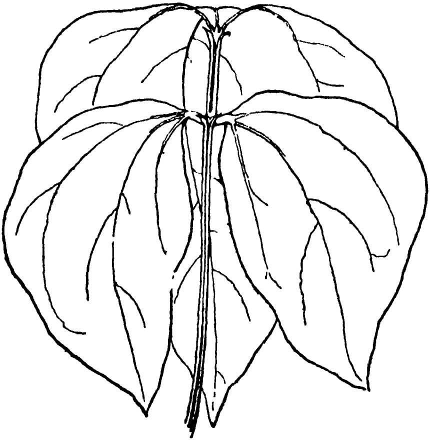

FIG. 27—Dwarf Bean night position, seen from the front. (Backs of all the leaves only are seen.)

Upon scratching or irritating the pulvinule of the terminal leaflet of either of these beans on its under-side, a downward movement very slowly begins and is continued for a considerable time—from twenty minutes to an hour or so. In one case, experimenting with a dwarf runner bean, the leaflet, whose tip I had arranged against a background which it just cleared, so that I might measure the extent of its fall was found ultimately to have fallen 1¾ inches from its original position. The left leaflet responded to the transmitted irritation by *erecting* itself, almost to the same extent as the terminal leaf fell, whilst the right leaflet remained practically unmoved.

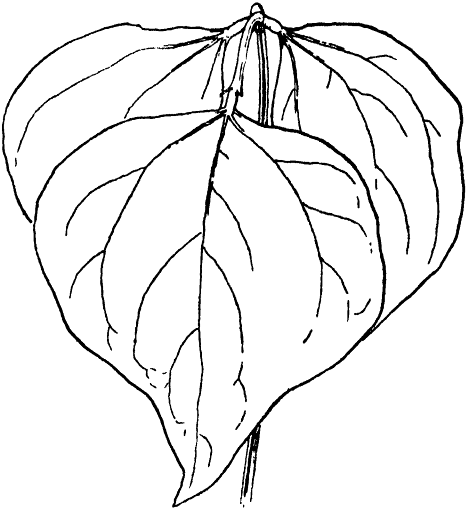

FIG. 28—Night position.

Another experiment with a scarlet runner bean leaf had a curious, and I think, a very instructive result. In order to ascertain whether there were any general difference in excitability between the right and left leaflets, as had seemed to appear from former experiments, I had made some trials as follows: I arranged a leaf with the terminal leaflet resting against an upright sheet of blotting paper, the lateral leaflets being free. I then pierced with a strong pin the pulvinules of both lateral leaflets on their *side* at the back, marking the course of the tip of each lateral leaf by dots of ink on the blotting paper as they responded to the irritation. In the case I am describing, both lateral leaflets moved *backwards*, towards the irritated point, till they touched one another. They hardly fell at all. Later on I found them expanded and apart again, and supposed the movement ended. But a couple of hours afterwards I found them again touching, other changes in their elevation having taken place, and the terminal leaf—which had moved upwards—having now descended below its original position. Later the lateral leaves were again quite apart, with further movement as regards elevation. Finally, at 7 p.m. (the experiment having begun at 11.45 a.m.) the lateral leaflets were again touching and the terminal leaflet drooping backward over them. This rhythmic movement three times repeated was very striking and reminded me of the slow folding back and opening of a pair of wings.

When we come to consider the theories of Sir J. C. Bose in the next chapter we shall see that this appears to be a very clear case of 'multiple response' to an irritation, and has important significations.

All was not ended yet, however. During the next day there seemed to be absolute exhaustion consequent on the excitement of the day before, and this continued through the following day, the lateral leaflets remaining touching one another and the ordinary movements of day and night scarcely noticeable. On the third day I pierced the pulvinules of the lateral leaves on the opposite side to the former punctures. In half an hour they moved apart towards the new source of irritation, and there followed two more repetitions of the rhythmic movements, associated with some up and down movement in all the leaflets, after which again followed days of exhaustion with side leaflets

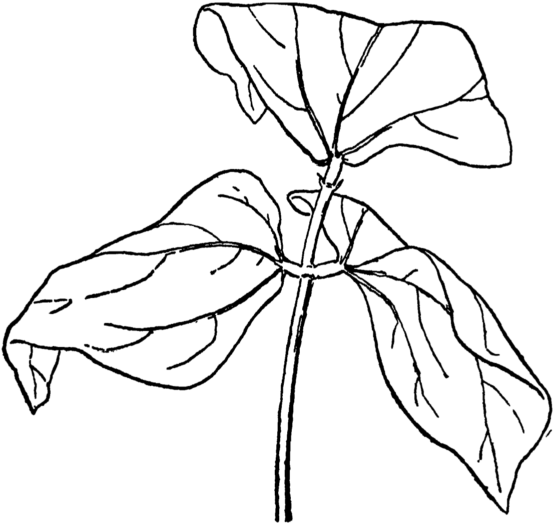

FIG. 29—Scarlet Runner which suffered from neurasthenia.

turned back and touching. A fresh irritation a week after the first produced the same results but responses seemed slighter and the exhaustion deeper. I continued the irritations at intervals and on the twelfth day the leaf suddenly seemed to take a new lease of life, the side leaves separating and all three leaves erecting and falling in a normal manner.

The only explanation I can suggest is that the repeated stimulus had in the end improved the tonicity of the leaf, which is one of Bose's theories. Altogether the history of this leaf has seemed too good an exponent of his views to be omitted. This leaf, after a series of repeated irritations, finally became entirely normal and ceased to fold its leaves backward. At the end of a month it was well and healthy. I have since discovered that these bean leaves, if taken off with the pulvinus at the junction of leaf with stem, *make roots in water*, as if they were cuttings, and so can live indefinitely. This property is a very valuable one for long continued experiment.

As will have been understood, bean-leaves have a definite diurnal rise and fall, independent of artificial stimulus, and the following still more interesting experiment was undertaken, partly in order to test for my own satisfaction the principle of Sir J. C. Bose's method of making plants record their own movements by means of a writing lever (as will be explained in the next chapter); partly in order to get a clear demonstration of this diurnal rise and fall of the leaf and to watch for accidental, subsidiary, or intentionally caused departures from this; and finally to ascertain what force the leaf had in its movements to pull a weight.

Using a small pair of balances (intended for photographic chemicals) with a strong upright from which a curved arm projected, supporting the balancing rod to which the scales were attached, I fastened a silk thread to one end of the balancing rod, passed the other end of the thread by means of a needle round the mid rib of the terminal leaflet of a dwarf bean leaf, about in the centre of the leaf from stem to tip and secured it by tying. I cut off the two lateral leaflets as they got in the way. The leaflet stood in a small bottle of water close to the scale on the one side, and I put a few pins into the opposite scale to act as a counterbalance so as to keep the thread taut when the leaf should rise. I now very carefully adjusted the position of the leaf and length of thread so that when the leaf was at its medium height the scales exactly balanced. There was a pointed indicator at the top of the balancing rod which helped to mark the exact amount of fall or rise of each scale.

This arrangement worked perfectly. During the morning the scale on the leaf side rose and that with the pins fell, and as the fall of the leaf began, the scale with pins rose as the other fell, touching bottom at 11 p.m. and having pulled the weight of 5 pins. I had been careful to arrange so that the pulvinule of the leaf faced the light on its upper surface, so there was no torsion or twisting as would otherwise have been the case; merely the up and down movement. I found the movement of the tip of the leaf measured as much as 3¾ inches from extreme of rise to lowest fall. Seven pins, weighing exactly 11 grains were eventually pulled quite to the bottom.

Next, in order to test the strength of an applied stimulus as against the light and other forces drawing the leaf up, I scratched the pulvinule on its lower side and afterwards applied a hot match to it, but not so as to burn or injure it. The result was a decided fall lasting two hours, after which there was a pause and then a rise, the scales, however, only mounting to balance before the fall for the night began.

Finally, wishing to see how far the immediate action of the stimulus of light was responsible for the force and movement of the leaf, I put the whole apparatus into a totally dark room for forty-eight hours. The scale which had begun to mark the daily rise, went gradually back to balance and remained there. On the following morning there was a very slight attempt at a rise during the early part of the morning, but the scale speedily returned to balance from which it did not move at all, the leaf being obviously at standstill. On the morning of the second day I brought it again into the light and in a quarter of an hour a rise began and the daily movements were carried on, though not with quite the usual vigour. By the next day it was working normally. Later I covered the pulvinule with black paper to prevent the action of the light on that part.

Movement almost ceased and I obtained a proof that the pulvinule is the sensitive part which mainly reacts to the stimulus of light.

The full meaning of the results of these experiments will be better understood after reading the following chapter. But I have thought it better to insert them here, rather than break the thread of what I have to say further on.

I have been greatly struck whilst working with these leaves, with the extraordinary *individuality* which they display. One bean-leaf is by no means like another bean-leaf either in character or behaviour, and in choosing individuals for experiment I found I could do nothing with them till I became acquainted with them and had formed some idea of their capabilities and disposition! To some I grew warmly attached and they seemed to respond to my stimulations and to allow themselves to be 'educated' in a way that was very attractive. Others were dull, slow-natured, and even apparently sulky! Some, I think, were more affected by weather than others, and there was a distinct difference in natural cheerfulness as well as in energy and activity. All this sounds so absurd that I should perhaps hardly have ventured to write it had I not come across some passages in Professor Thomson's *System of Animate Nature* which corresponded so closely with my experience that I felt encouraged to record what I had noted. "The movements of one animalcule", he remarks, "are often quite different from those of another even in the same medium, so soon is the note of individuality struck;" again: "Two individual Planarias (small ciliated fresh-water worms) often react in opposite ways to the same stimulus. . . . After long study of Planaria, Professor Pearl concludes that 'it is almost an absolute necessity that a person should become familiar, or perhaps better, intimate, with an organism, so that he knows it in something the same way that he knows a person, before he can hope to get even an approximation of the truth regarding its behaviour.'"

Much of course can be explained by outward causes as Professor Thomson acknowledges, "their freshness or fatigue, their recent stimulation and degree of excitement, and their history," but I am glad to find some support for that which has been borne in upon me during the months that I lived in daily communion with my bean-leaves, that there is more than the mechanical even in the common little vegetable of our kitchen garden!

CHAPTER VIII

RESPONSE. ITS MEANS AND MEANING

SINCE the works of Sir J. C. Bose on this one subject of response in the plant comprise at least half a dozen large volumes, packed with accounts of experiments and minute investigations, it is difficult to give a clear and simple account of his theories and explanations in a short compass. However, as his work seems to be at the 'growing point' of knowledge, so to speak, it is well to try to understand what he considers has been revealed to him by Nature in answer to his persistent questionings; and it certainly sheds a flood of new light upon the silent and apparently unresponsive vegetable world around us.

He devoted himself, in the first place, to the work of inventing machinery which should enable him to register with accuracy the movements of the sensitive plants which were his first study, under the influence of various stimuli. The necessity for such machinery will be vividly brought before the mind of anyone attempting to observe the movements of leaves without appliances. It is indeed impossible to be accurate in such observations without mechanical apparatus, and serious work could not be attempted in such conditions.

By attaching the long petiole of the leaf of Mimosa to one arm of a carefully balanced lever of extreme lightness, having a small weight at the other end to act as a counterpoise, and depending from its centre a long, fine wire, bent at the tip to act as a recording pencil, and then by setting the latter in regular motion by electricity, tapping out its record on a moving plate of smoked glass falling at a definite rate, he obtained an accurate register of the curves of fall and recovery made by the leaf, and at the same time an exact record of the time taken in each part of the movement, which was shewn by the spacing of the dots which were made by the 'pencil' at a known rate—say one-tenth of a second. With apparatus on this principle he was able to make the plants on which he operated record their own history and shew the effect of his irritations whether by blow or scratch, by heat or burn, by light or chemical agency, or by electric current; he could watch the rapidity and degree of their response, and compare results in different cases. His machinery in general for experimental purposes is far too complicated and intricate for me to attempt to explain, or in many cases, to understand. Its ingenuity and delicacy is extraordinary, and his power of manipulating fragile objects and fine mechanism must be marvellous.

Working with these aids he soon came to the conclusion that no matter what the stimulus might be, in every case where it was applied directly to the plant in moderate degree, the plant itself being in normal condition, the result was a contraction of the protoplasm and a discharge of fluid from the cells, rendering them less turgid or full of sap. The discharged fluid which went into the tissue between the cells, was usually driven like a minute wave to the opposite side of the irritated organ, causing that to swell and become more full of moisture. This general movement caused the fall of the Mimosa leaf, the under part of the stem contracting and the upper part expanding. This was the normal effect of every stimulus in whatever shape. By using another invention of his—a delicate electric probe—he discovered that the contraction under stimulus of any part, always went with a condition of galvanometric negative electricity; the opposite condition being always associated with positive electric sign.

These two conditions of contraction and expansion with flaccid and turgid results respectively, and a negative or positive electric response, seem to lie at the root of almost all responsive movement in plants, and—as far as they go—explain many difficult matters, though of course they themselves need explaining, for why should the protoplasm contract or shrink at a touch, and discharge its superfluous moisture?

Bose found that by using the electric probe upon ordinary—apparently unresponsive—plants he obtained the same results of negative and positive electricity as with the sensitive plants whose movements he could test at the same time. Why then did the former not respond outwardly by movement? He found that it was a case partly of mechanical apparatus, but mainly of balance of forces. In the Mimosa the under side of the so-called pulvinus—that is the cushion-like swelling where the leaf stalk is attached to the stem, which we remarked on in the runner-bean—is at least eighty times as sensitive as the upper side; if, therefore, you irritate the stalk in any way, the contraction will be far stronger on the under side and will pull down the leaf. If the stalk were one of an ordinary plant—say a wallflower—the contraction in response to the irritation would be equal all round, and there would be a real but minute shortening of the irritated stem, which you could not measure or perceive without special apparatus. This shortening under stimulus has been observed and measured by Pfeffer in the irritable stamens of Cynareæ, which are not anisotropic, or unequally sensitive on the different sides, like the Mimosa.

Bose finds an extraordinary analogy between the response of muscle in the animal and that of the plant under stimulus, and it is mainly on the subject of his wide generalizations in this direction that he is called in question by other botanists. But this leads us to the subject of his investigations into the local centres of sensitiveness in the plant which seem to answer to the nerves in the animal. By means of his electric probe which is inserted very gradually into the petiole or stem under investigation in such a manner as to irritate as little as possible, and with pauses for recovery from such inevitable excitation, Bose has felt his way carefully into the tissue. At a certain exact point he found a definite electrical variation. The probe is insulated except at the tip, so that he could detect the precise spot where the change began, and on going deeper, where it declined. By this means he discovered a sensitive layer around the stem, which he found to be the part responding to stimulus. This perceptive layer proved to be the sheath of the cells containing starch granules, which are the reserve food of the plant laid up for future use, when they will be transformed into a sugar.

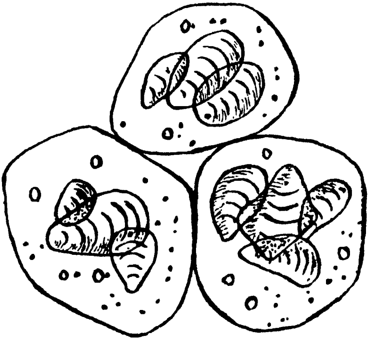

FIG. 30—Cells from potatoes containing starch granules.

At this point we can make an interesting test for ourselves, which will at any rate help us to grasp his theories. Let us take the flowering stem of a wallflower, forget-me-not, snapdragon, or any shoot of a soft, quickly-growing plant—a common young nettle if we like, and lay it *on its side* with its cut stem in water. After some hours—perhaps a night—in this position, if we look at it we shall find the tip of the shoot erected perpendicularly whilst the rest remains horizontal. One's first impression is that it is drawn upward by the light. But try the experiment of keeping the shoot entirely in the dark, and you will find the same thing has happened. How is this to be explained?

Bose gives a quite simple and clear explanation: the starch granules, he says, which now lie uppermost in those cells of the cylindrical layer just described fall to the lower side of the cells and press by their own weight against the inner part of the sensitive sheath which holds them, causing it to contract. The starch grains in the segment of the cylinder lying nearest the ground fall *away* from the more sensitive part of the sheath and therefore the contraction in the upper part causes expansion here, and a sort of elbow is made in the stem, the end of the shoot being erected. This is called geotropism, being an effect of the pull of the earth, so to speak, upon the heavy starch granules.

There is much variation in this response according to the season and to the condition of the plant. This seems to be due to the presence of starch grains at a favourable season in the plant's life and their disappearance later (when they have probably been used up in the flowering or seeding effort).

We have spoken of a balance of forces, and this is going on all the time; temperature, light, the pull of the earth upon heavy particles in the cells, all these acting and reacting upon the sensitive ‘neurine’ as some botanists call it, of the plant, and causing it to take a certain exact position and to perform certain movements. Let us consider one or two examples:

In the side branches or leaves of a plant the attitude may be almost horizontal, and one asks why they are not obliged by geotropism to grow perpendicularly. The answer appears to be that the upper surface of such branches or leaves has gradually become less sensitive than the under side, owing to the constant action of the sun rays which by continued stimulus induce a kind of ‘fatigue’ and exhaust their capability of reaction. Now if such branches be placed in a vertical position, the starch grains in that cylindrical band press downwards and against the bottom and sides of the cells, exerting *equal pressure* on the sensitive layer at each side of the stem; but that which was the lower side being more sensitive, reacts more strongly and there is contraction and downward movement. When this has carried the branch or leaf below the horizontal, the starch grains in the upper half begin to press heavily on the neurine and those in the lower half to fall away from it; at a certain point this counteracts the former reaction and there is contraction of the upper side and upward movement. A balance is thus established between the two forces, and the angle of the leaf or branch depends on the exact degree of difference of excitability of the two sides. I do not say that these are the sole two forces acting on the leaves or branches to fix their position—far from it—but these opposing stimuli play a decided part, and shew us the secret balancing that is going on beneath the surface. Take another case. A very large number of plants have a diurnal movement of their leaves, depending on light and temperature and geotropic action. We can watch it for ourselves in the acacia (so-called), the bean, the oxalis, and numbers of other leaves; some fold upwards and some downwards, some move several times a day, and some, like the bean, as I have observed in my own experiments, appear to be in almost constant motion. The Mimosa pudica is of the last-named kind, and the history of its daily movements in India seems to be as will follow. I must explain that a rise of temperature checks geotropic action and a fall increases it; in other words (possibly through some difference in the starch granules themselves, affecting their weight) during the heat of the day leaves and stems of growing plants are much less sensitive to gravity, or the pull of the earth on the heavy particles in their cells, whilst during the cooler hours this is increased. On the other hand increase of light acts as a stimulus and raises the leaf of the Mimosa, whilst diminution of light causes it to fall. Under the influence of these conditions the movements of the Mimosa leaf proceed thus: From 2 p.m. to 5.30 p.m. the leaf gradually rises owing to the lessening temperature permitting some geotropic action, also to the effect of light; after 6 p.m., as the light fails the leaf falls till 9 p.m., after 9 p.m., as temperature lessens further, geotropic action once more resumes normal sway in spite of want of light and the leaf rises, and is at its highest at 6 a.m. After that there is a struggle betwixt increasing light drawing the leaf up and increasing heat minimizing geotropic action and encouraging its fall; the latter wins, and the leaf falls till about 2 p.m.

For the sake of simplicity I have had to omit many confusing elements in my attempt to give a general view of some of Sir J. C. Bose's theories and the results he obtained, but it is necessary to make a few observations with regard to the different effect of stimulus according to its strength and to the condition of the plant stimulated. I have said that a moderate stimulus of any kind given to a plant in a healthy condition produces contraction and discharge of water from the cells, with a negative electrical response. But a feeble stimulus may produce the opposite effect of expansion with increase of turgidity and positive electrical response. I have spoken of the ‘ positive ’ electrical response with its accompanying increase of turgidity and expansion as if it were the effect of the wave of fluid driven out by the contraction of cells during the ‘ negative ’ response which is the ordinary one replying to any stimulus. But though I think this is held by some botanists, it does not seem to be clearly proved that this is the full explanation, and it is certain that when a feeble stimulus is given the positive response with expansion *may alone appear.* In ordinary cases the two responses are found to exist, though the positive is the feebler and is often masked by the negative. This is all at present very debatable ground and the exact nature of the positive response is not definitely known. By some it is thought to be probably merely a hydro-mechanical impulse (result of a wave of fluid driven forth); by others it is considered to be probably of the same nature as the negative response, a physiological impulse conveyed by the neurine of the plant. Very strong stimulation may, on the other hand, give rise to a series of responses one after another, spoken of as 'multiple response', of which I imagine my opening and closing bean-leaf, mentioned in the last chapter, is an example. A stimulus repeated with insufficient rest for recovery will cause 'fatigue' and insensitiveness for a time in the leaf or organ under experiment. My bean-leaf may again furnish an example. Again the condition of the plant and its circumstances have to be taken into account. In a plant in a sub-tonic condition a moderate stimulus may produce expansion instead of contraction, acting in the same way as a feeble stimulus, but in many cases of want of tonicity in a plant it has been found that a moderate stimulus often repeated *restores* tone. I refer once more to the last phase of my bean-leaf experiment.

A highly sensitive plant suddenly brought into a dark room may lose its sensitiveness entirely for a time, owing to the sudden diminution of light. In very wet weather the Mimosa is often found to be unable to respond to a stimulus by the usual contraction, owing to the excessive turgidity of its cells. Cold will also cause an insensitive condition, and warmth will increase the sensitiveness. All these considerations, and very many others which I cannot go into, give us an idea of the interplay of action and reaction which brings about the varying positions and movements of the leaves and stems of plants. Nothing is without cause, though the latter may be entirely hidden from us, and Bose is careful, I think, to make it clear that he regards the plant as a delicate *machine* whose mechanism is of the same kind and quality as that of animal muscle, but which, in his view, possesses neither instinct, spontaneous action, nor consciousness. He brings out a number of striking analogies in plant reactions to stimulus with those of animal muscle. A few of these shortly put are as follows:

1. The response to stimulus varies in plant tissue and animal muscle according to the force of the blow or irritation, and exactly in the same way. There is the same contraction of protoplasm with expulsion of fluid in both, as the result of direct stimulus.
2. There is the same exhibition of fatigue in frequently excited parts if too little rest is given between.
3. On the other hand there is a possibility of 'educating' a sensitive tissue in a plant or a muscle to increased activity by repetition of the stimulus with suitable intervals.
4. There is transmissibility of excitation from one part when irritated to distant parts along

certain parts of tissue in the plant answering to the nerves in the animal. The fact of transmission is not doubted by anyone, but some botanists are not in agreement with Bose as to the manner of transmission, but this subject is too complicated for the present discussion.

5. The same stimuli applied to vegetable and animal have a similar effect: for example ozone has a stimulating effect on both; carbonic acid gas depresses; ether at first excites and then depresses; chloroform is a stronger narcotic and insensibility in the plant may last six hours. Death ensues if prolonged, and wee drops of moisture are forced out in this case by the violence of the contraction from the cells of the plant, and stand on the surface. The points of similarity in death-spasm of plant and animal are very singular.

Nitrogen monoxide, or laughing gas, has little effect on a plant, but may be slightly stimulating, but nitrogen dioxide, sulphuretted hydrogen and sulphur dioxide are all extremely toxic and their vapour brings about the death of the plant. Vapour of alcohol sometimes enhances excitability for a short time; after this it depresses.

6. Sensitiveness is increased by heat and diminished by cold. The rate of response under increasing heat is progressive both in plant and animal up to a certain limit, after which neither of them undergoes any further increase in response.

7. The sensitiveness of a plant to electrical stimulus may in some cases be actually ten times as great as in a human subject.

8. The pulsation in certain plants such as Desmodium gyrans has a strong analogy with the animal heart. The rapid down movement represents the systolic contraction and the slower up movement, the diastolic expansion of the muscle of the heart. In the plant it is due to alternate contractions of the lower and upper side of the pulvinule; the lower half contracts, rapidly recovers, and the upper half contracts.

The cause of this pulsating movement, Bose explains, is related to that of the 'multiple response' to a strong stimulus; that is, the energy absorbed is held latent in the tissue of the plant and finds its expression in regular pulsations. If the plant is kept continually in the dark where it can obtain no fresh energy or stimulus from light, the pulsation ceases. If the body is kept persistently without resource of energy from food, the pulsation of the heart ceases. Carbonic acid gas arrests pulsation in both cases.

Bose explains the ascent of sap in trees and plants as due to a rhythmic pulsation of excitation propelling the water along the channels of tissue from cell to cell. He considers that the excitation is begun at the root and is due to the pressure of the growing points against the rough earth, to the absorption of water, and possibly to certain chemical stimulants in the soil. He thinks that evaporation from the leaves of a plant may to some extent assist in the movement of sap by relieving pressure, but he says it cannot be the cause, because the sap continues to rise though the atmosphere be saturated. The main cause, he maintains, is rhythmic propulsive force, which may possibly be likened to that of the action of our heart, depending, he says, upon derived energy, like all other movements and responses in plants.

The phenomena of growth he would put in the same category as the result of rhythmic protoplasmic activity dependent upon energy held latent in the tissue and obtained through all the usual channels of natural stimuli. This rhythmic motion which appears to be so widely existent in both plant and animal life and to lie at the root of so many phenomena exhibited by them, reminds us of the rhythm of leaf arrangement, and once again we feel the hidden order and meaning beneath all the apparently careless greenery! It is strange, but true, that even a common bean-leaf may be rising and falling with an ordered sequence and a force that we could never have guessed, like the muscle of our heart. I was struck by this when making the experiment recorded in the last chapter with a bean-leaf tied to a balance. I saw that the diurnal rise was very slow like the diastolic expansion of the heart, and the fall far quicker, corresponding to the systolic contraction, and that these two movements alternated regularly within the twenty-four hours, so long as the leaf was in health and not interfered with by other irritations or stimuli.

One more point which remains to be explained is the cause of the right or left-handed spirals made by tendrils and similar growths, and the twisting of twining stems. I am unwilling to attempt any detailed and lengthy account of Bose's views in this respect because I think they do not lead at present to any definite and clear conclusion, and he himself remarks that the subject is extremely complex. He explains simple torsion or twisting of leaves or stems towards the light as due to a 'law' by which the least sensitive of two surfaces of unequal sensitiveness is made to face the stimulus—whether of light or any other agency. But this is not an explanation of the spiral growth of which we are speaking. He bids us remember that twining growths always occur in stems or organs which are anisotropic, or unequally sensitive in their two halves, and he says the spiral growth is due to the relatively greater growth of one of the two sides which causes the spiral torsion to right or left; but exactly how this unequal growth is excited or in what way it proceeds is not made clear, and probably is not understood.

Shortly, then, it would seem that Bose regards all these wonderful movements in plants which he has discovered and tested by his extraordinarily delicate and carefully planned experiments, and by means of his mechanical inventions in machinery, as purely reducible to *response to stimulus*. He has traced this universal 'response' to the inorganic world, where he finds it operating, and he links it on again to the animal 'machinery' and believes that there is a wonderful unity through all. One thinks of the Life-Force working in and through this machinery. " A body hast Thou prepared me " it seems to cry, and the unknowable in plant or animal—that which lies beneath the mechanical response, causing the variation of reply in the individual apparently subjected to the same stimulus—this, perhaps, eludes the most careful investigation of the searcher into mechanism, and makes its own secret response to some higher call of the Life-Force, beyond the purely physical.

As with Darwin's great discovery of ' Natural Selection ', so with this law of ' Response to Stimulus ', one doubts if *all* the facts are covered. To take just one example. The story told by M. Paul Levy of the behaviour of other climbing plants in the presence of the murderous fig called Matapalo of Guiana, sounds at first like a ' traveller's tale ', but it is accepted by Professor E. Morren, Professor Taylor and others. This terrible fig throws its arms around the tree upon which it intends to establish itself, clasping in its deadly embrace all that may chance to be growing previously upon the victim, and throttles all beneath it, rearing itself upon the gaunt frame of its murdered support. Now the strange thing is that, according to M. Levy, creepers already growing upon a tree attacked by Matapalo make the most strenuous efforts to uncoil themselves and escape before their terrible foe becomes strong and large enough to surround them with his embracing arms. " The most strangely twisted forms may be seen " says M. Levy " amongst the creepers endeavouring thus to fly from the deadly fig." M.

Levy assures us that the creepers of those forests of Guiana have strange predilections for certain trees, and will refuse to make use of those they do not like, even though they be conveniently near at hand. They avoid them, carefully pursuing their way until they find a host that pleases them, when they speedily attach themselves to him.

Is there nothing here but response to mechanical stimulus? It is hard to believe it. Yet exactly how the Life-Force acts upon the plant we cannot know at present, and must be content with such indications as we may find of some ultra-physical working.

Botanists seem to be disturbed by Sir J. C. Bose's findings as to the likeness in the response of plants to that of animal muscle. But need they be anxious? Once for all the plant and the animal separated their destiny at the beginning, and it seems that henceforth they can never be in the same line of evolution. But it is the same Life-Force working in both. Is it surprising if the same laws and results appear in the history of each?

If we go back to our model fir-cone and consider the two sets of coils forming the secondary spirals, the one running to the right and the other to the left, we shall find that they can never follow along each other's path; they are for ever separate and distinct. Yet follow the spirals that start from No. 1. and proceed with a difference of eight between the scales in one direction and of five in the other. Upon scale forty-one, behold they are one, and just for the moment there is union and clasp of hands. This will of course recur at eighty-one and again at one-hundred-and-twenty-one, and so on. Does this tell us nothing? Does it not shew us what all Nature is singing around us, that there is indeed unity in the midst of diversity, and that the one great Central Spiral holds all the secret of our being and of its good creation.

THE END

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